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1955 MEAN MONTHLY WIND SUMMARY ALONG RECONNAISSANCE TRACK NORTHWEST OF HAWAIIAN ISLANDS AT 500 MB.

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ABSTRACT

The mean 1955 monthly variation of the zonal and meridional wind components, and the wind steadiness are presented for the 500-mb. level, from 20°–40° N. in the longitude of the Hawaiian Islands. The basic wind information used in the construction of these charts was obtained from the daily weather reconnaissance flight on the track designated "Petrel Foxtrot." Mean monthly 500-mb. wind charts were also prepared for the Hawaiian Islands area from the same wind sample.

1. INTRODUCTION

Almost no climatological information about the wind field is available over the oceanic region to the north of the Hawaiian Islands. Mean monthly summaries of winds from sailing ships still provide the most detailed surface wind information (Werenskiöld [1]). The only existing upper-level wind information must be derived from mean contour charts (U. S. Weather Bureau [2]).

Meteorological data are being obtained daily by reconnaissance flights to the north of the Hawaiian Islands. In the past, reconnaissance data to the north of Hawaii have been taken at various flight levels and over several different flight tracks. During 1955 one flight track designated "Petrel Foxtrot" was flown regularly. The daily Petrel Foxtrot outbound, or low-level, leg was flown at 1,500 feet, and the return, or high-level, leg was flown at 500 mb. Observations were taken daily at fixed geographic positions on the flight track. This daily source of wind information provides the basic data for a mean monthly wind summary.

In this study, only the 500-mb. reconnaissance winds were considered. The winds were observed at 100-mile

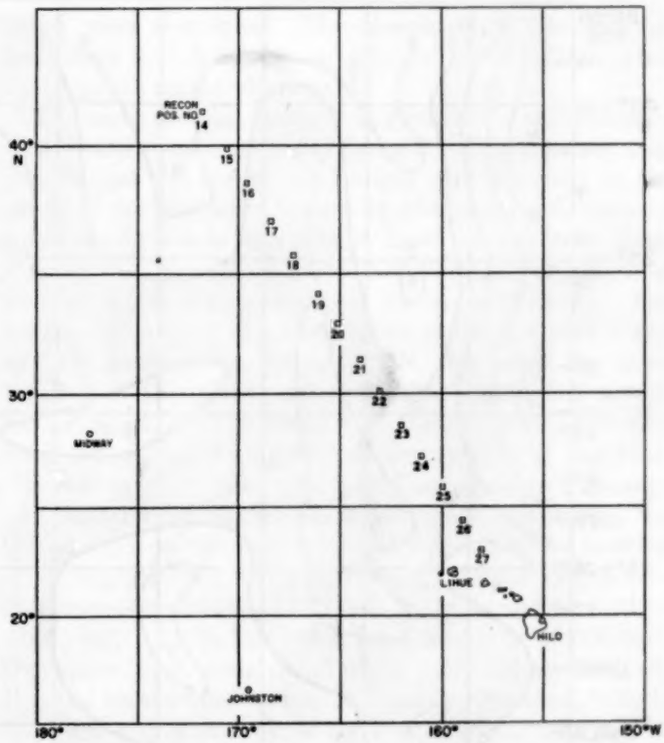

FIGURE 1.—Location of "Petrel Foxtrot" reconnaissance positions at 500-mb. north of the Hawaiian Islands during 1955–1956.

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[2] Present affiliation—Florida State University.

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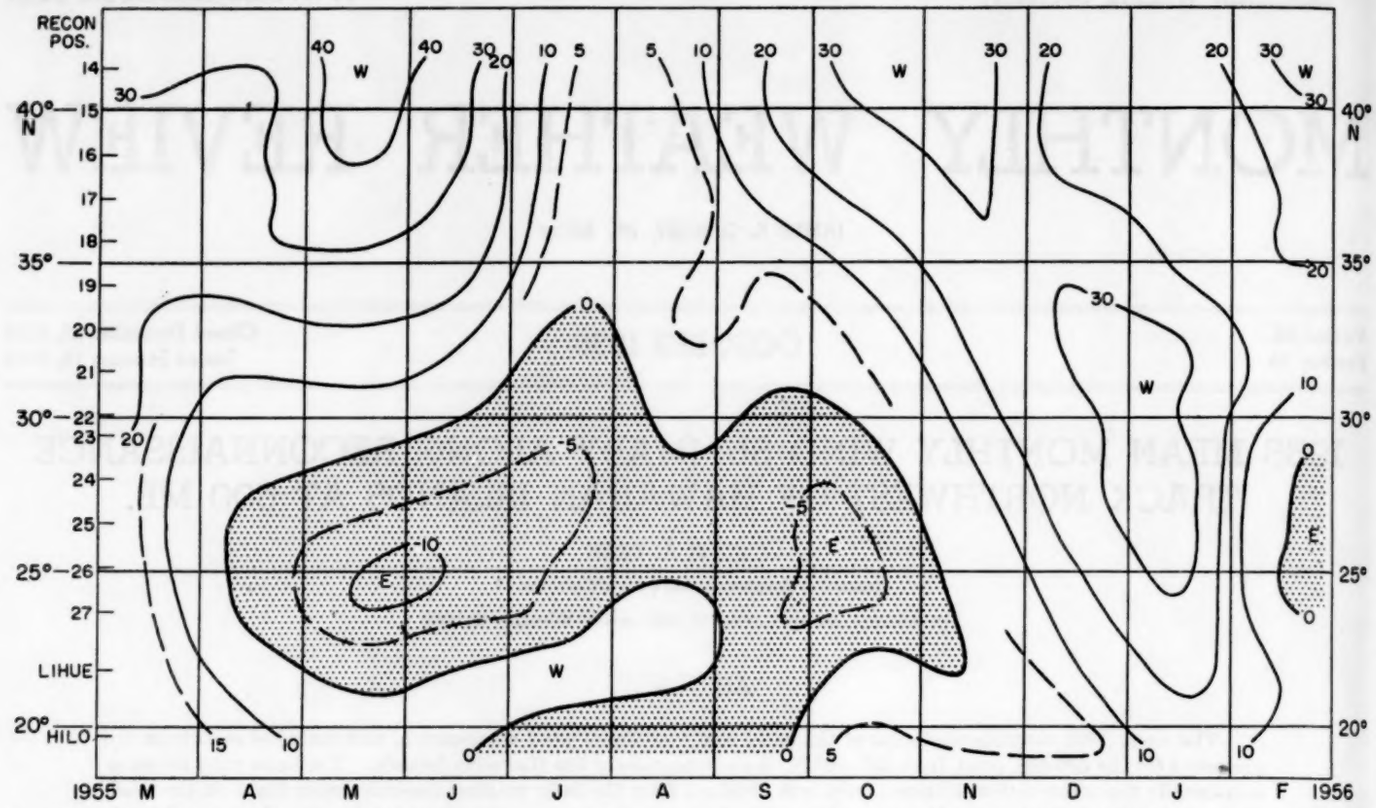

FIGURE 2.—Variation of the east-west wind component by latitude and month at 500 mb. between 155° and 170° W. during 1955-1956 (knots).

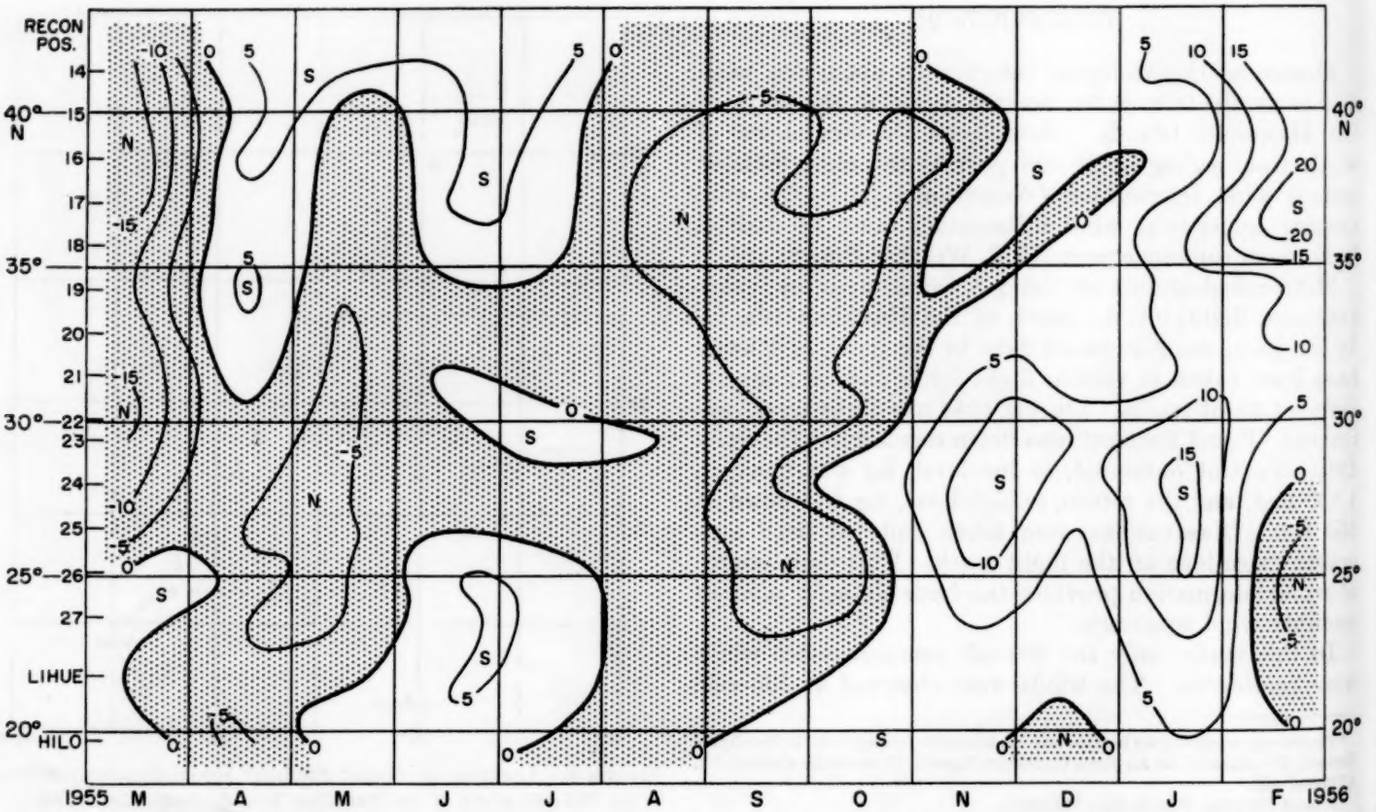

FIGURE 3.—Variation of the north-south wind component by latitude and month at 500 mb. between 155° and 170° W. during 1955–1956 (knots).

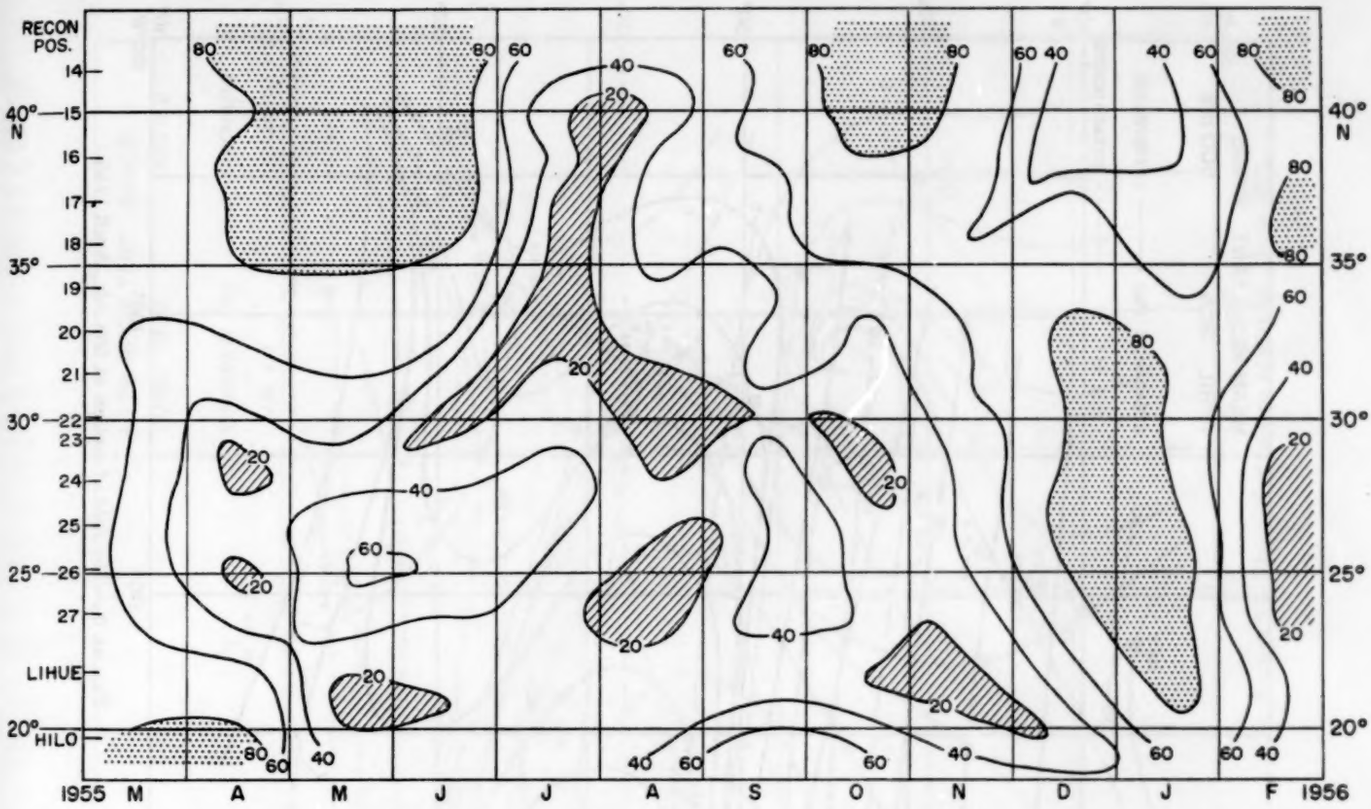

FIGURE 4.—Variation of the wind steadiness by latitude and month at 500 mb. between 155° and 170° W. during 1955–1956 (percent).

intervals between position 14—the northernmost position on the track (near 2345 GMT) and position 27—southernmost position (near 0615 GMT) (fig. 1). Double drift wind observations were made when possible at all positions. However, the Petrel flight track length and duration in time were such that for the last 500 miles (positions 23–27), the wind observations had to be based upon loran fixes because of darkness. Loran winds are average winds usually taken over a 100-mile distance on reconnaissance flight and are, therefore, applicable to the mid-point position. On occasion some average winds had of necessity to be taken between positions 14 and 22 due to cloudy weather conditions. Such average winds were few in number and have been included statistically as though they were double drift winds, thereby sacrificing some data accuracy in order to maintain a larger sampling of cases.

2. ANALYSIS OF DATA

All 500-mb. wind observations for individual reconnaissance positions were tabulated by month. In addition, the 0300 and 1500 GMT 500-mb. winds for Lihue, Hilo, Midway, and Johnston were compiled. The winds were then processed to obtain the following wind parameters: $\bar{u}$, the mean east-west wind component; $\bar{v}$, the mean north-south wind component; $\bar{c}$, the mean scalar wind speed; $|\bar{\nabla}|$, the mean resultant wind speed; and $\bar{s}$, the mean wind steadiness. The steadiness of the wind as used here is defined as the ratio of the resultant wind speed to the scalar wind speed.

The mean monthly latitudinal variation of the east-west wind component is shown in figure 2. This chart demonstrates that the ocean area around and especially to the north of the Hawaiian Islands at 500 mb. was dominated by westerly winds throughout most of the year 1955. During the months, April to October, an enclosure of easterly winds appeared within the westerly winds. The northern boundary of the enclosure (between westerly and easterly winds) located near 30° N. represents the mean location of the subtropical anticyclonic belt. Of significant interest was the absence of the anticyclonic belt in these longitudes during the winter months of the year. The southern boundary of the enclosure (between easterly and westerly winds) was located near Kauai during the period April to October 1955 and represents the location of an upper level cyclone or trough, oriented east-northeast—west-southwest, south of the subtropical anticyclonic belt. At higher levels, for example at 30,000 feet, the upper-level trough was often more clearly defined. It could be observed to stretch from the Marshall Islands eastward and often entered the United States over southern California (Riehl [3]).

During the winter, mean maximum speeds north of Hawaii at 500 mb. ranged from 25 to 35 knots; however,

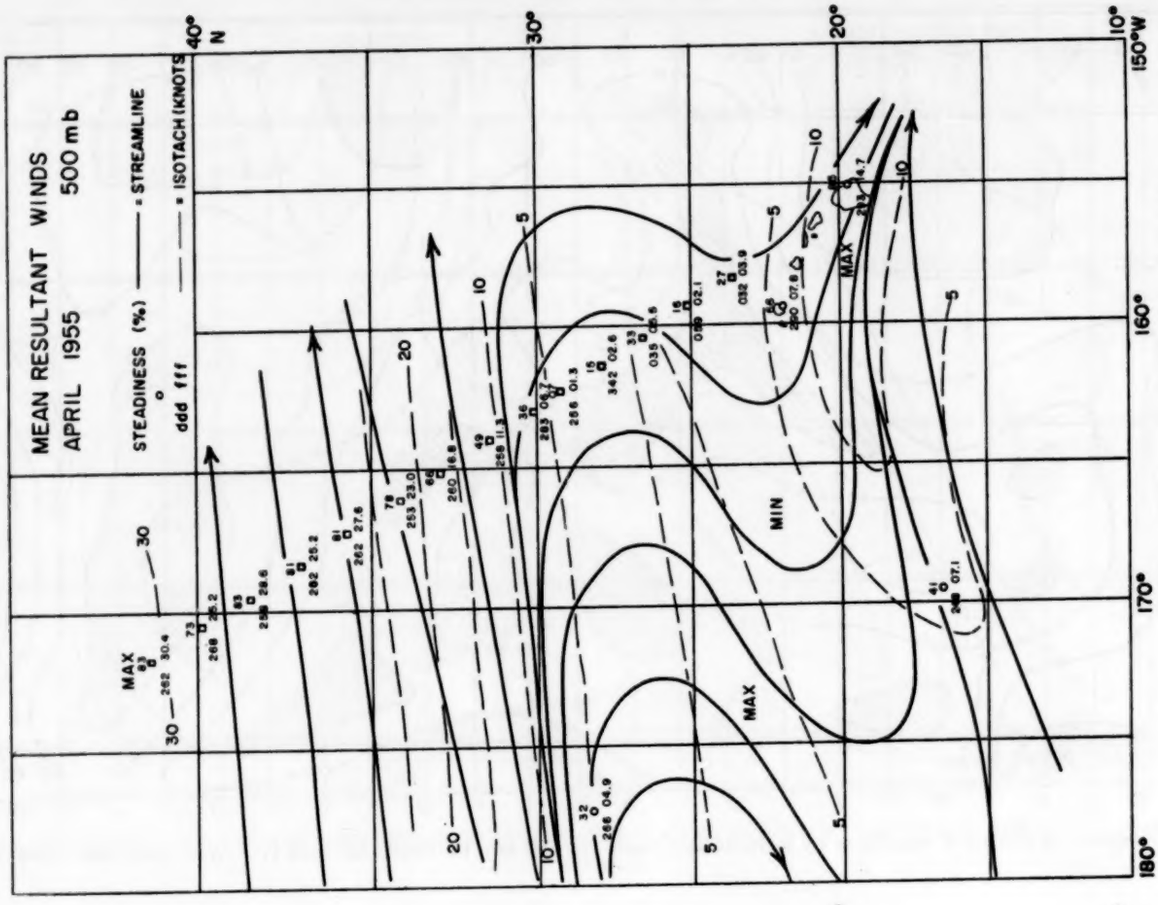

FIGURE 6.—The field of motion at 500 mb., April 1955.

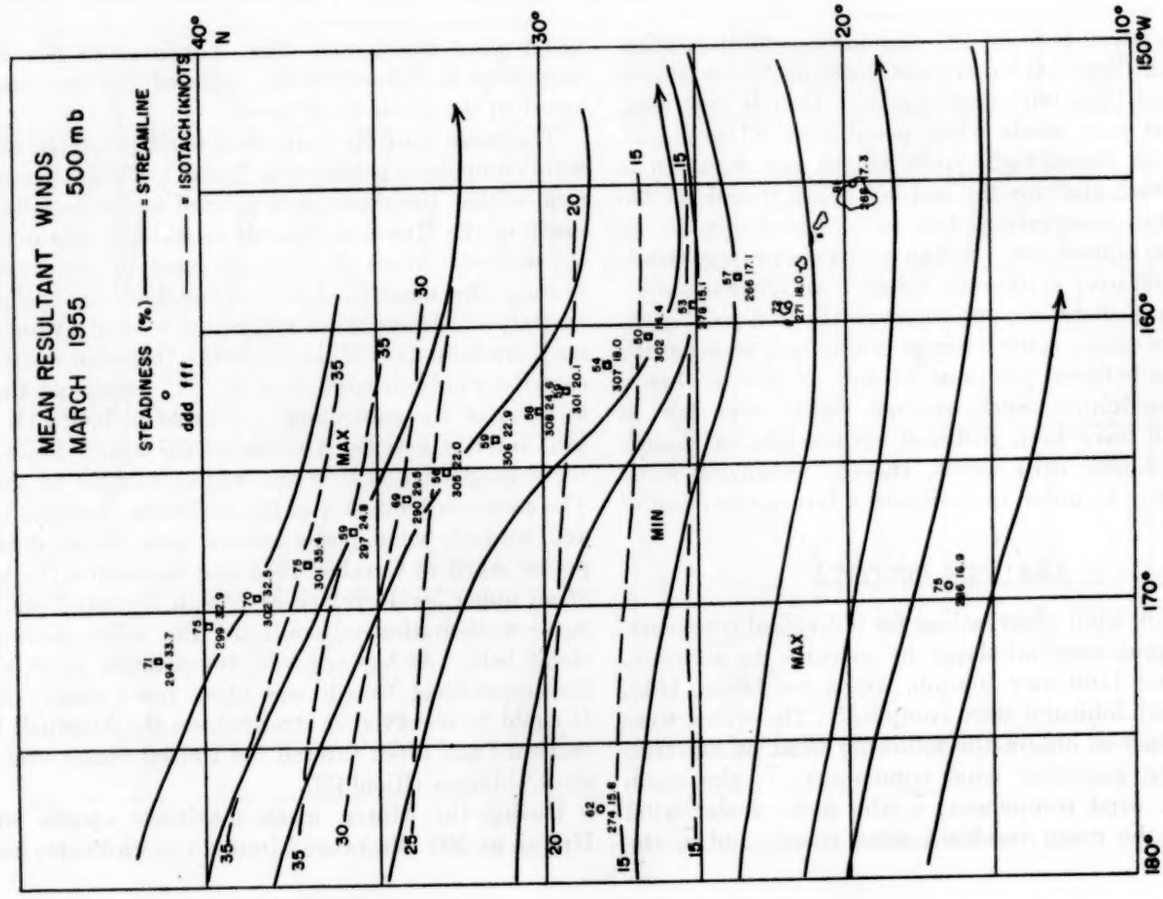

FIGURE 5.—The field of motion at 500 mb., March 1955.

FIGURE 8.—The field of motion at 500 mb., June 1955.

FIGURE 7.—The field of motion at 500 mb., May 1955.

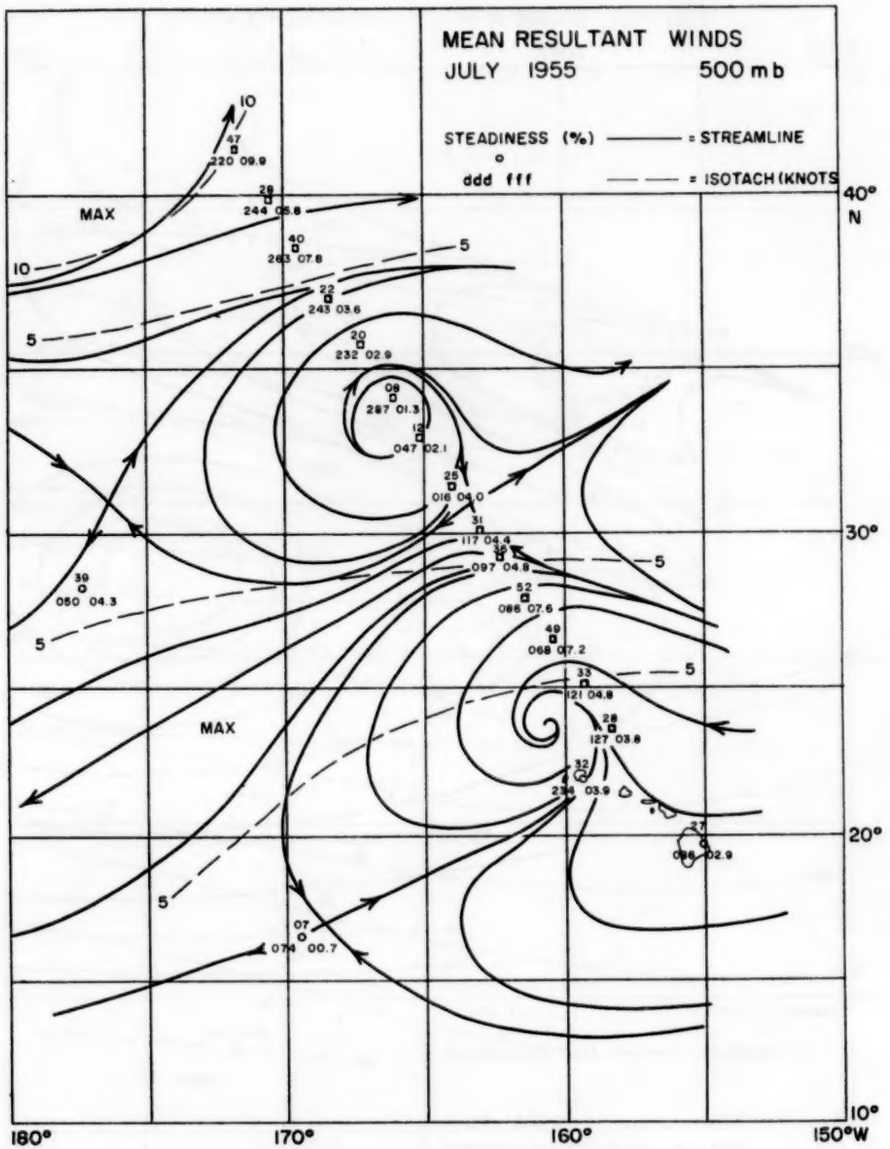

FIGURE 9.—The field of motion at 500 mb., July 1955.

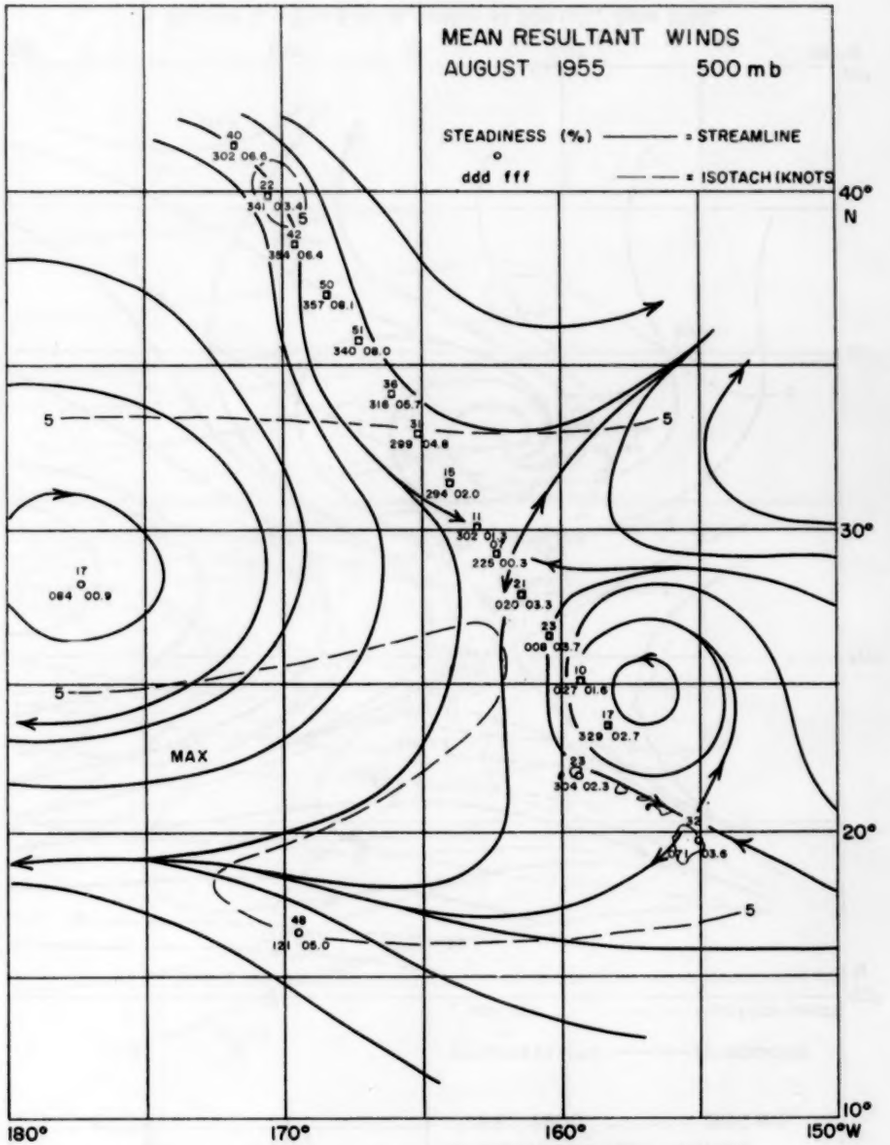

FIGURE 10.—The field of motion at 500 mb., August 1955.

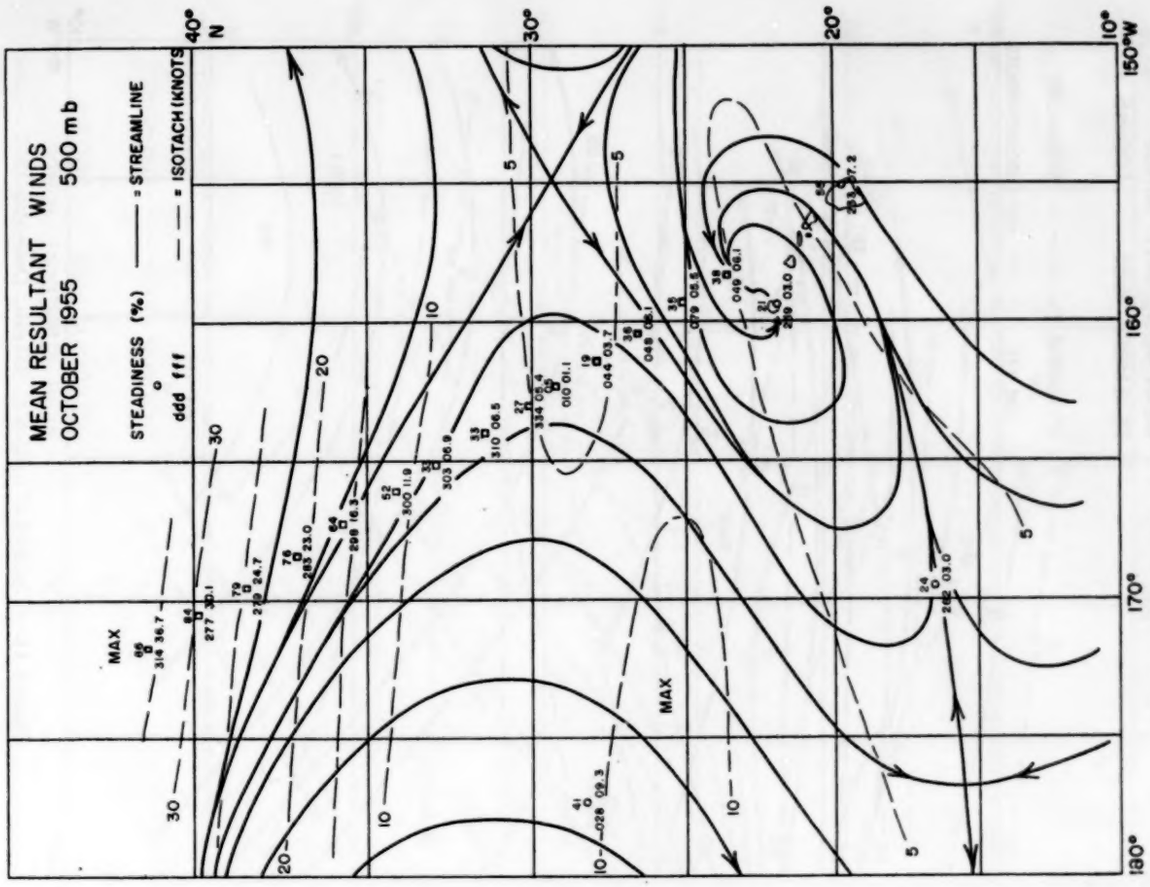

FIGURE 12.—The field of motion at 500 mb., October 1955

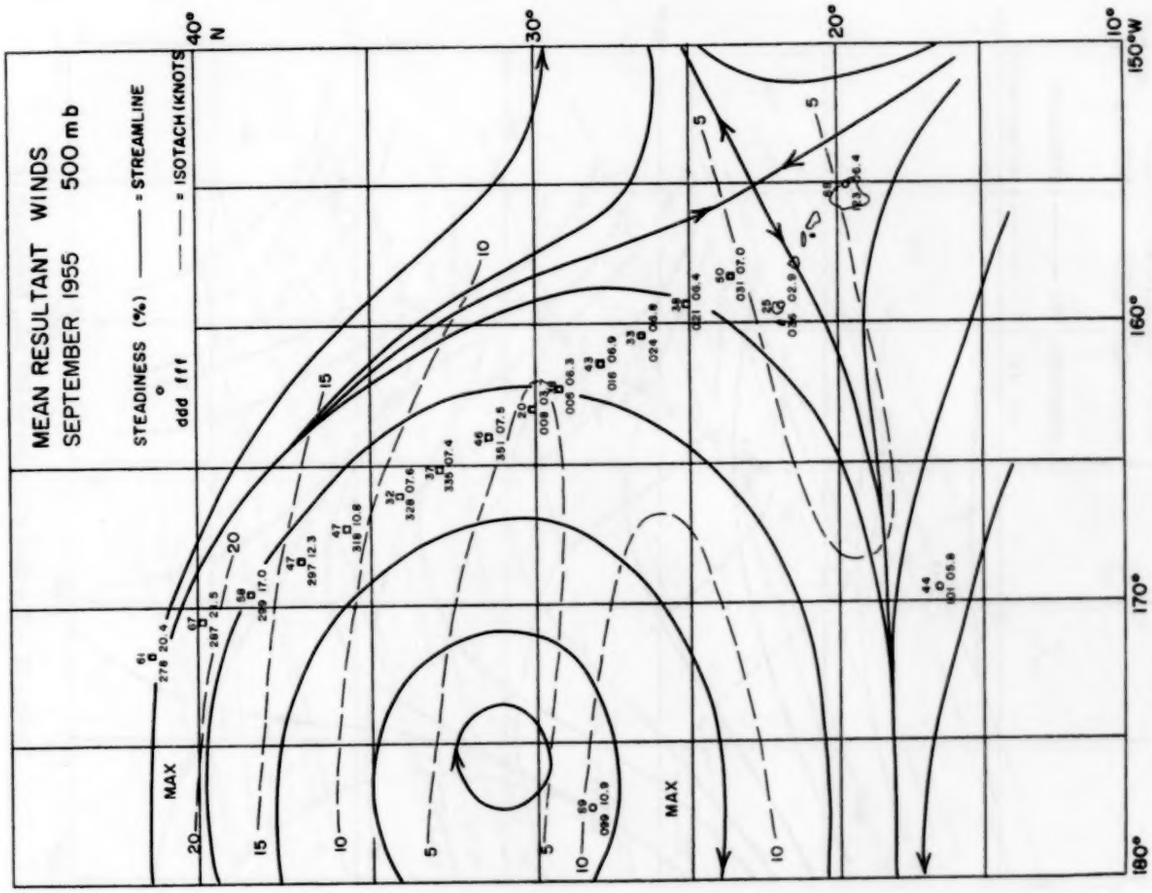

FIGURE 11.—The field of motion at 500 mb., September 1955.

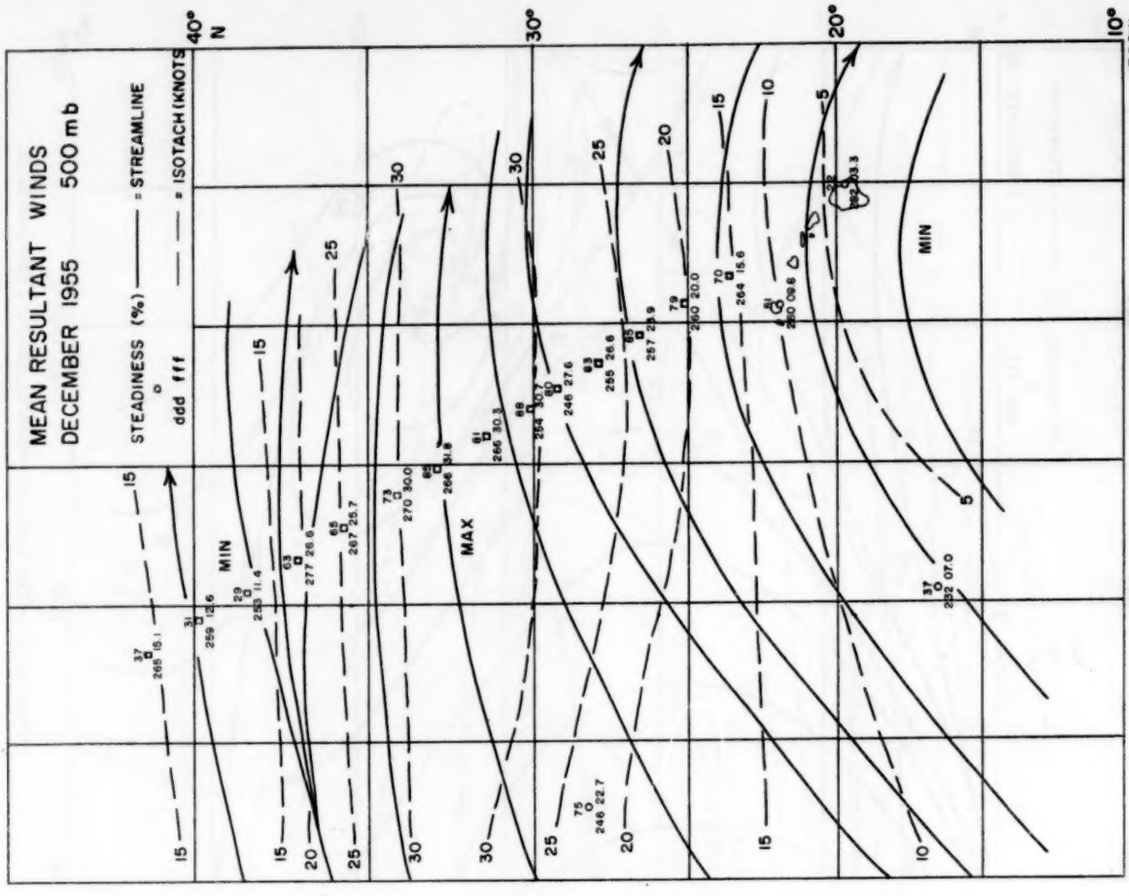

FIGURE 14.—The field of motion at 500 mb., December 1955.

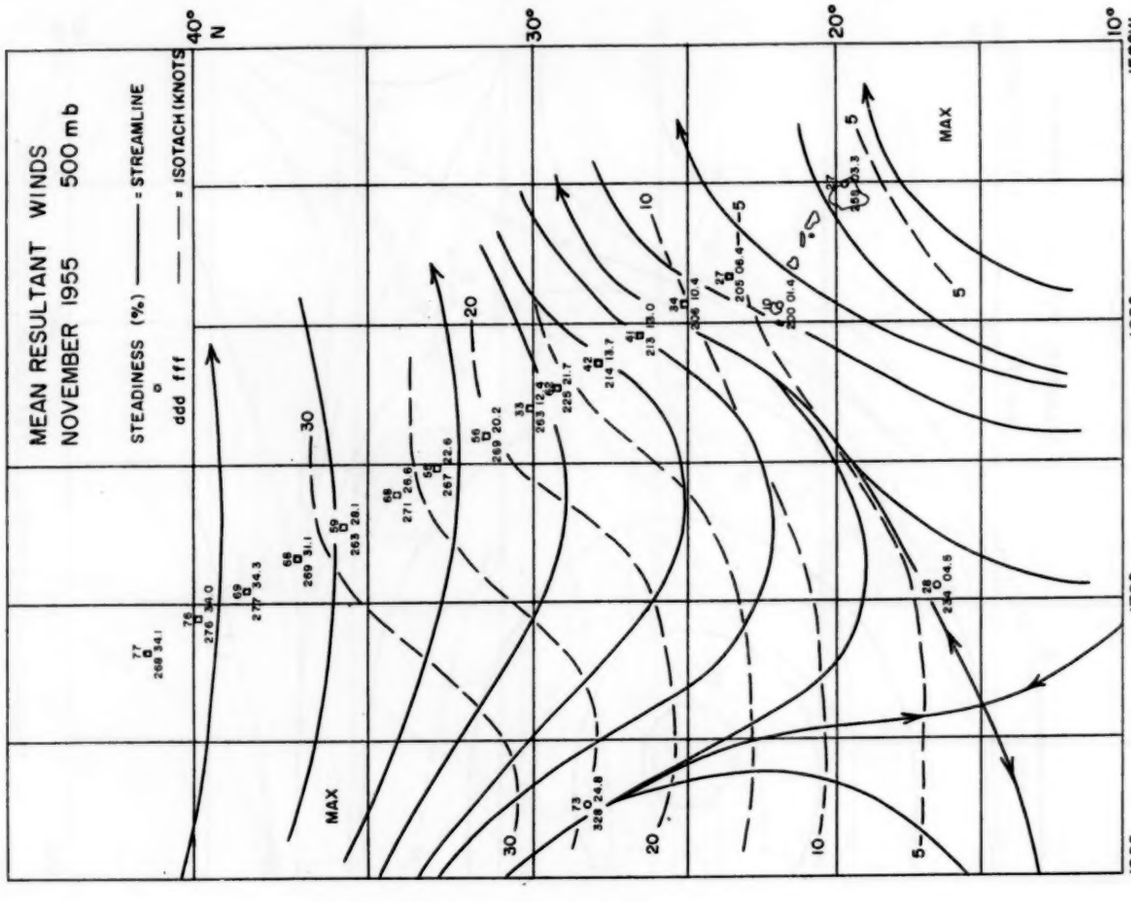

FIGURE 13.—The field of motion at 500 mb., November 1955.

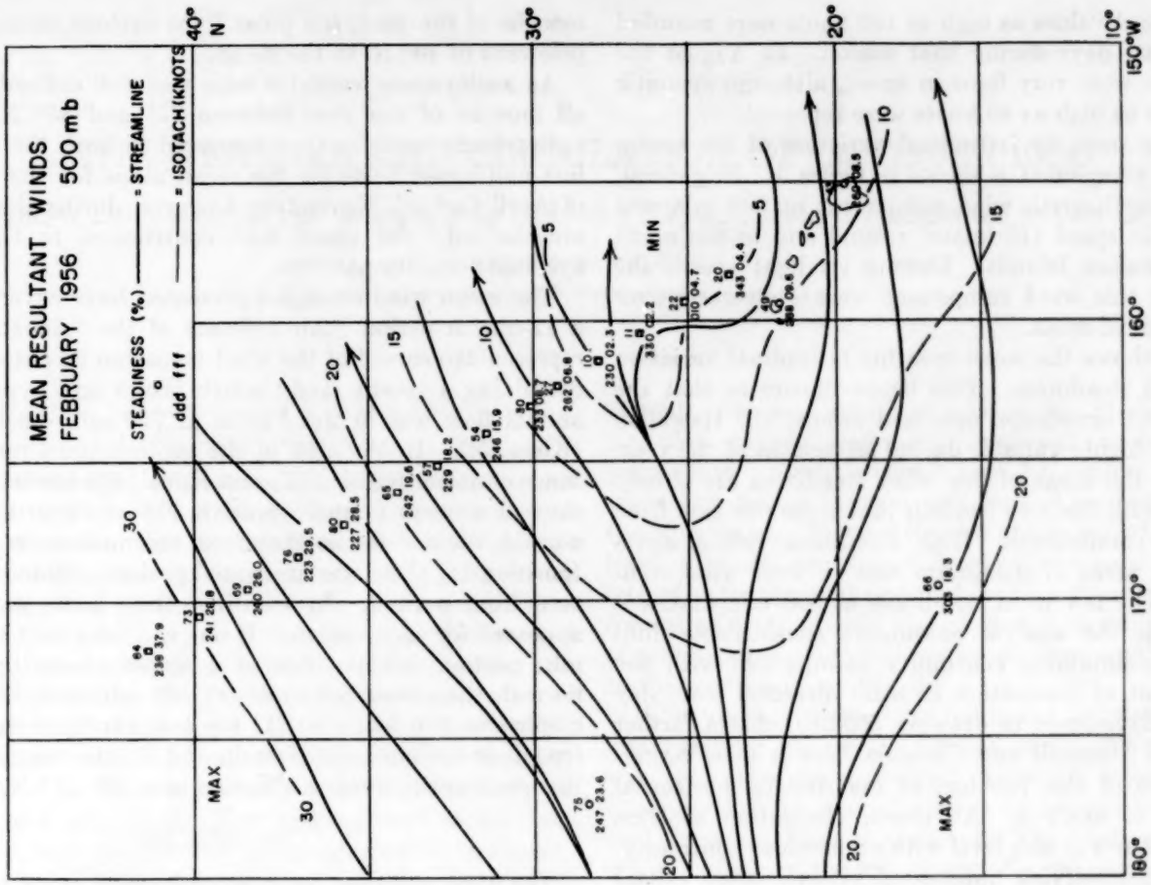

FIGURE 16.—The field of motion at 500 mb., February 1956.

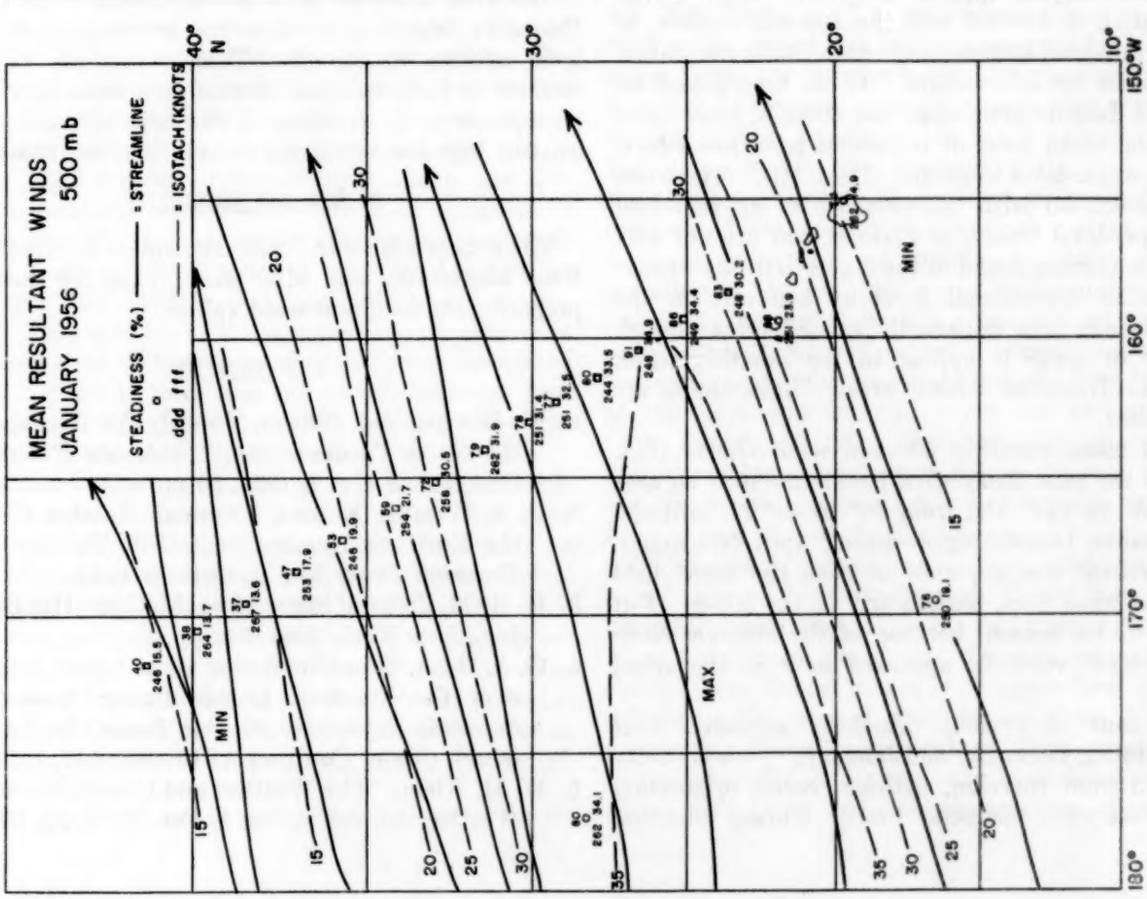

FIGURE 15.—The field of motion at 500 mb., January 1956.

synoptic speed values as high as 100 knots were recorded on individual days during that season. In August the mean winds were very light in speed, although synoptic wind speeds as high as 40 knots were reported.

The mean monthly latitudinal variation of the north-south wind component is shown in figure 3. In general, the mean north-south wind component at 500 mb. was not strong in speed (10 knots) around and to the north of the Hawaiian Islands. Despite its light speed, the patterns of this wind component were systematic over large latitudinal areas.

Figure 4 shows the mean monthly latitudinal variation of the wind steadiness. This figure illustrates that the 500-mb. wind circulation over and around the Hawaiian Islands was highly variable during all months of the year. In general, the areas of low wind steadiness are closely associated with the zero isopleth that separates east from west wind components. High steadiness values correspond with areas of maximum east or west wind components. The low wind steadiness at 500 mb. makes it evident that the analyst encounters considerable difficulties in maintaining continuity (compatible with the large amount of fluctuation in wind direction from day to day). Experience in drawing 500-mb. charts farther west in the Marshall and Caroline Islands area verifies the presence of this problem of maintaining horizontal continuity in analysis. At times, circulation systems appear on charts at this level with no previous continuity. Evidently, intensifying upper-level systems often extend their circulation downward into the 500-mb. surface, or intensifying low-level systems may extend their circulation upward into the 500-mb. surface. It has been shown for the Marshall Islands area, that the 500-mb. level often represents the mean level of transition from lower-level easterlies to upper-level westerlies (Dean [4]). The westerlies are associated with the presence of an east-west oriented upper-level trough or cyclone, and are not part of the wind maximum found in the higher-latitude westerlies. A similar transitional level at 500 mb. in the Hawaiian Islands area apparently existed often enough synoptically to make it appear in the monthly mean charts for the Hawaiian Islands area. These charts are discussed below.

The 1955 mean monthly 500-mb. wind charts (figs. 5–16) depict the most likely wind circulation over an area from 150° W. to 180° and from 15° to 40° N. latitude. In the Hawaiian Islands region during April–November, cyclonic vorticity was apparent in both the speed field and the streamline flow, particularly in the latter. But during the winter season, because of the stronger basic current, cyclonic vorticity appeared only in the speed field.

Another zone of cyclonic vorticity appeared near 35°–40° N. during December and January. This vorticity area resulted from traveling cyclone centers originating in conjunction with the polar front. During all other months of the year, the polar front cyclone centers were poleward of 40° N. in the mean.

An anticyclonic vorticity zone was well defined during all months of the year between 25° and 35° N. This anticyclonic vorticity area appeared in both the streamline and speed fields on the mean maps for the months of April through November; however, during the winter months only the speed field contributed to the anticyclonic vorticity pattern.

The mean wind examples presented have covered only a 12-month period. An estimate of the "climatological representativeness" of the wind maps can be obtained by examining a recent study which shows how typical the annual flow was in the Pacific at 700 mb. during 1955 (Klein [5]). In the area of the southernmost reconnaissance position (position 27, near Kauai) the contour values showed a mean annual negative 50-foot departure from normal, while at the northernmost reconnaissance position (position 14) there was an annual positive 200-foot departure from normal. In addition, these same anomalies appeared for each season. If one can infer that the 500-mb. contour heights showed a similar departure from normal, then the wind charts at 500 mb. probably overemphasize two features: (1) the magnitude of the mean trough or cyclone over Hawaii, and (2) the magnitude of the mean anticyclonic circulation near 30°–35° N.

3. CONCLUSIONS

The 1955 monthly mean 500-mb. wind maps over the Hawaiian Islands area show the presence of an upper-level cyclone or trough. These maps are of special interest to meteorologists in that area since they provide an equatorward extension of the field of motion to the existing high-latitude mean 500-mb. contour charts.

ACKNOWLEDGMENTS

The author wishes to thank Mr. Julius Korshover, Miss Rose Wakukawa, and Mrs. Susan Yang for their aid in preparing the resultant wind values.

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THE WEATHER AND CIRCULATION OF OCTOBER 1956[1]

Including a Discussion of the Relationship of Mean 700-mb. Height Anomalies to Sea Level Flow

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1. WEEKLY CIRCULATION STATES RELATED TO DROUGHT RELIEF

As October began, critical drought conditions prevailed over most of Texas, the Central Plains, and southeastern Rocky Mountain States. Moisture deficiencies, particularly during the growing season, had mounted to record proportions in some areas; e. g., western Texas was already in its sixth year of drought [11]. Unirrigated crops had been a failure, pastureland of little use, and there was insufficient moisture for germination of seed for winter small grains.

First week.—Salient details of the first week in October are pictured in figure 1. Over North America the gross features of a ridge in the West and a trough in the East continued, as in September, to be the overriding characteristics [3]. Warmth predominated over the United States with ridge conditions along the eastern Rockies (fig. 1a) and heights well above normal aloft. The eastern North American trough was stronger than normal and off the coast in the north, although it lay inland over the Appalachians in the south. At sea level (fig. 1b), a maritime high pressure ridge extended from the Far Northwest to the Central Plains. With the exception of extreme eastern Texas and central California, no precipitation of note occurred west of the Mississippi-Ohio Valleys (fig. 1d). Widespread rains in the East were due to cyclonic activity in the Appalachian trough. The rather unseasonal California precipitation was associated with entry of a cold front into the closed California Low shown in figure 1a. No appreciable drought relief was experienced in central United States.

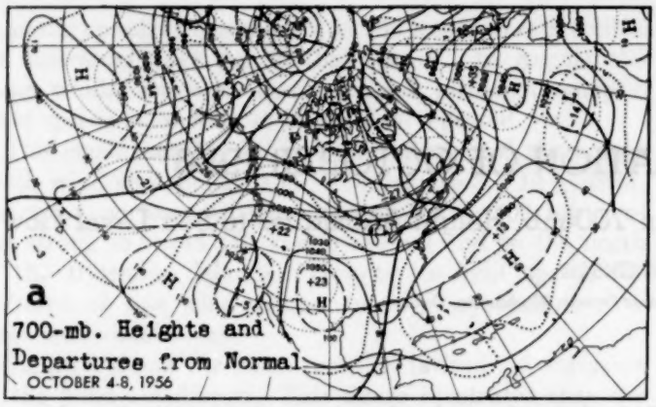
Second week.—Significant changes in circulation became manifest toward mid-month. During the last five days of this period (fig. 2a and b) mean ridge conditions at 700 mb. moved rapidly northeastward toward the central Appalachians. The closed Low off the California coast (fig. 1a) was gradually transformed into a vigorous polar trough. The entire west coast was now subjected to the effects of westerly perturbations which gradually extended their area of influence to lower United States latitudes.

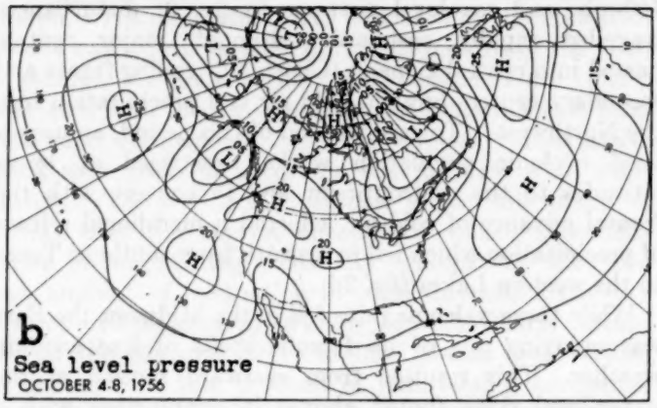
In the fast westerly band across the North Pacific (cf. 700-mb. and sea level patterns in fig. 2) disturbances travelled rapidly eastward. Although major centers passed into central Canada (Chart X), trailing fronts and secondary centers brought cold air and precipitation into the Northwest. Toward the end of this period, an upper-level cyclonic circulation worked eastward at lower latitudes to the midcontinent and in concert with the frontal advance of cold air, effected a meridional release of precipitation which fell in a swath from southern Texas to the western Lakes (fig. 2d).

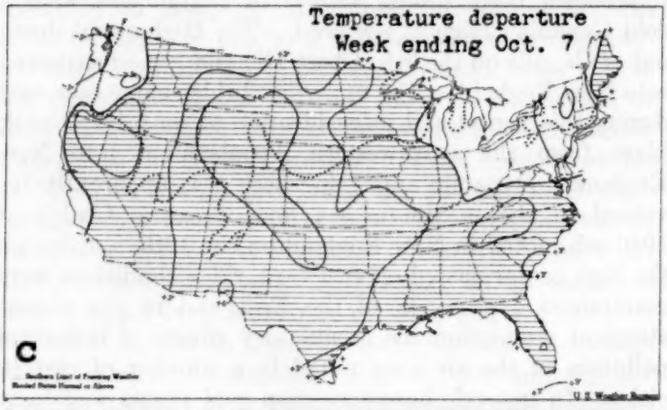
While these welcome rains fell in the Midwest, the East was enjoying one of its famous spells of fine autumn weather. This resulted from eastward motion of the upper-level ridge (noted above) in conjunction with a cold Canadian High at sea level. The High swept down out of Canada on the 9th (Chart IX) and passed eastward into New England. The upper-level ridge came eastward during this period and intensification at both levels took place from the southwestern Appalachians into New England. Dynamic anticyclogenesis was apparently involved in the maximum sea level pressure (daily) of 1040 mb. noted in New England on the 12th. Although the high center passed off eastward, ridge conditions were maintained over much of the East and in the almost stagnant circulation the cumulatory effects of industrial pollution of the air were noted in a number of eastern cities. In general, however, crisp cool nights and hazy autumn days were the order, except in those more southerly areas where onshore easterly flow to the south of the ridge line brought cloudiness and precipitation (note Florida, fig. 2d). Simultaneously the mid-United States was warmed by return flow to the rear of the High, but the East remained below normal due to the initial low temperatures of the Canadian air.

Third week.—Further extension of weak westerly influence into central and southeastern United States was noted during the third week. (See fig. 3a for latter part of week.) Most noteworthy event was the slow movement across the southern United States of an upper-level cyclonic circulation which spread precipitation from New Mexico eastward. Central and southern Texas received 1 to 2 inches generally, and temporary local drought relief was accomplished (fig. 3d). Heavy amounts of rainfall were

[1] See Charts I–XVII following p. 377 for analyzed climatological data for the month.







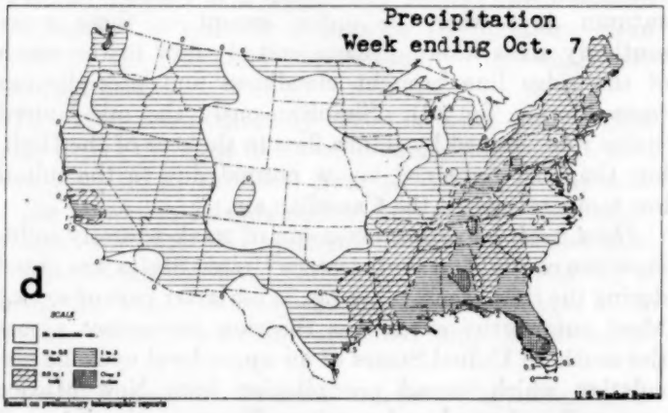
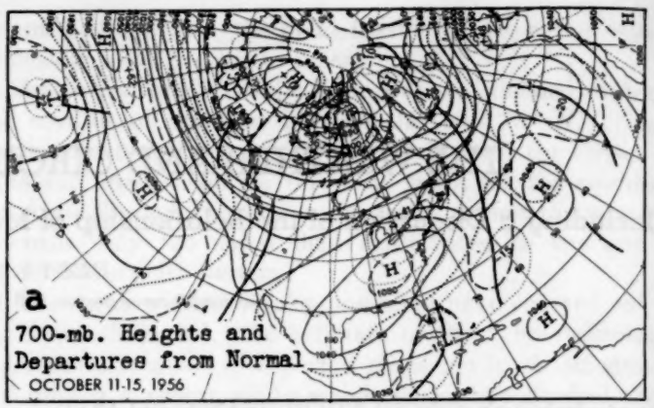
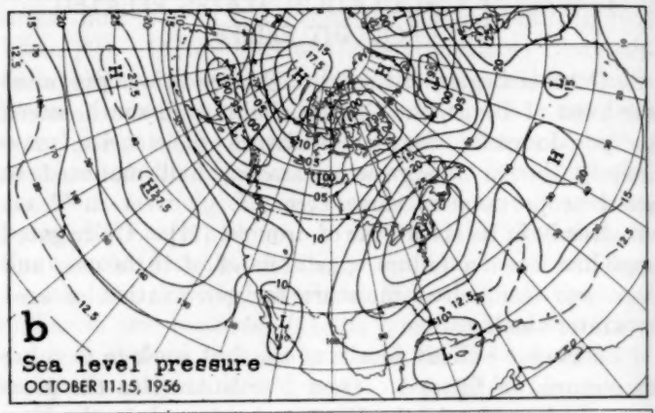
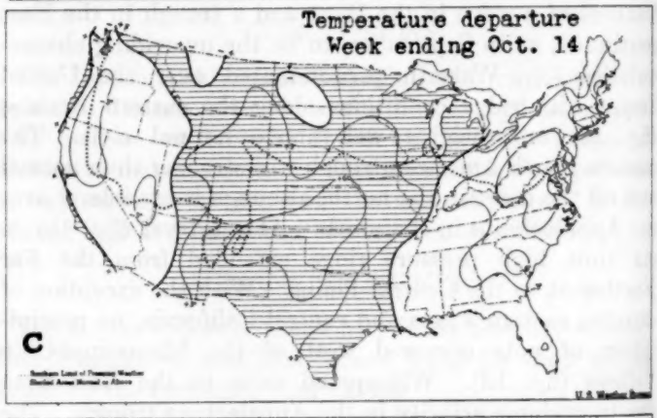


FIGURE 1.—(a) and (b) 5-day mean 700-mb. and sea level charts showing continuation of September pattern of mean ridge west of Continental Divide with mean trough along or off the east coast. (c) and (d) show continuation of September's temperature and precipitation regime with no drought relief in central United States.







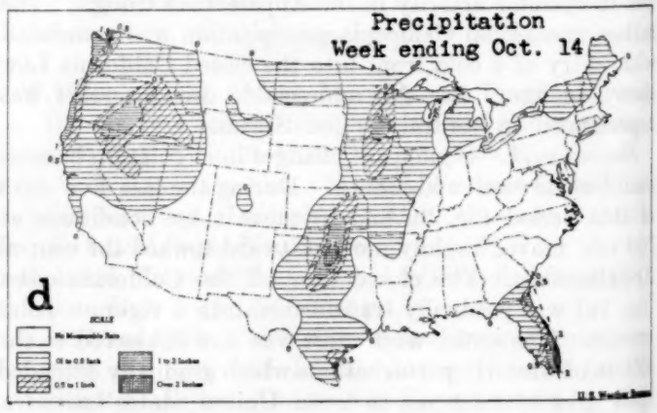
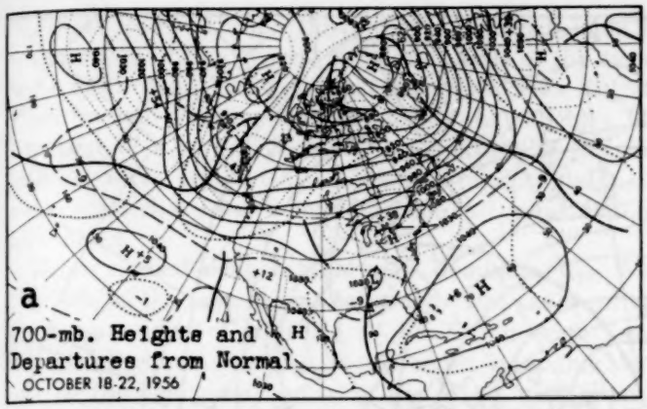
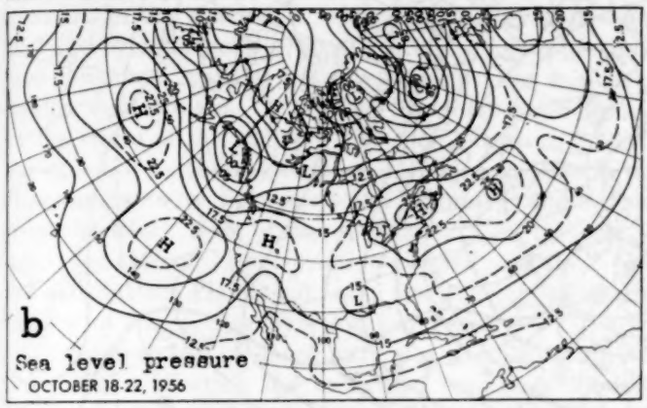
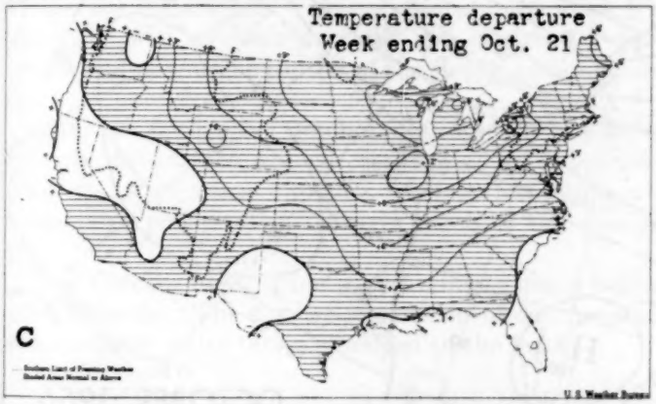


FIGURE 2.—Major changes in circulation pattern took place toward middle of month. Development of west coast trough and rapid motion of mean ridge into Northeast (a) and building of dynamic anticyclone in New England (b) brought changes in temperature regime, (c) and first Midwest drought relief (d).







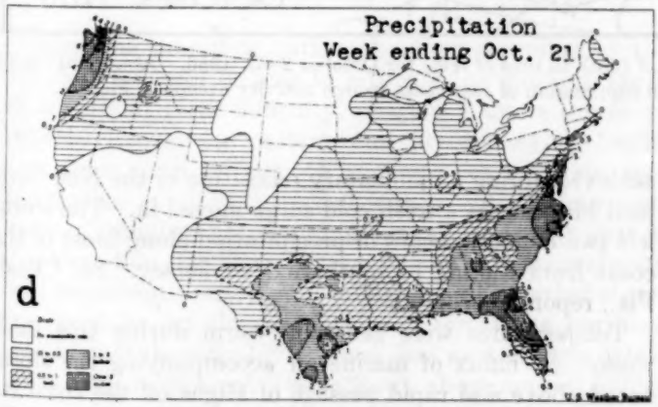
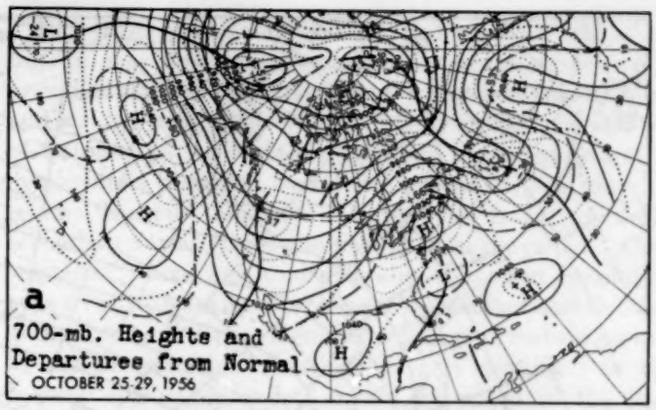
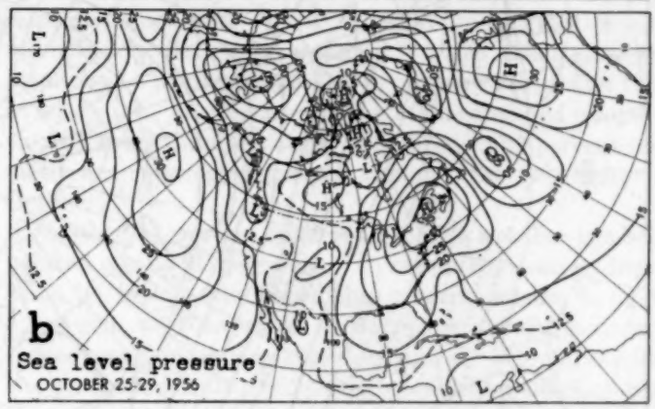
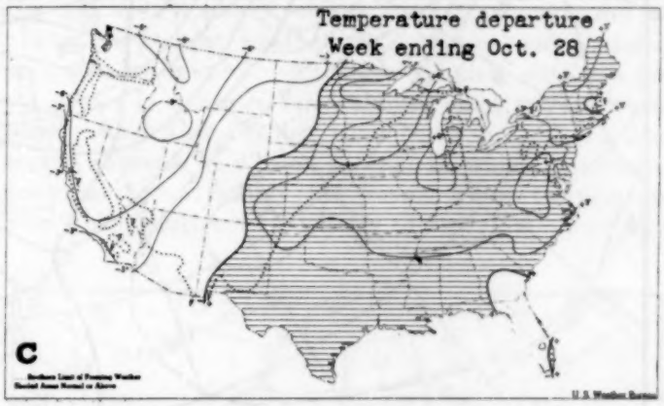


FIGURE 3.—Gradual penetration of influence of the westerlies into central and south-central United States during third week is indicated in (a) and (b). Warming in west (c) accompanied southerly anomalous flow (a). Precipitation in Texas seems most closely related to passage of upper-level cyclones. Note east coast precipitation due to semitropical Low.







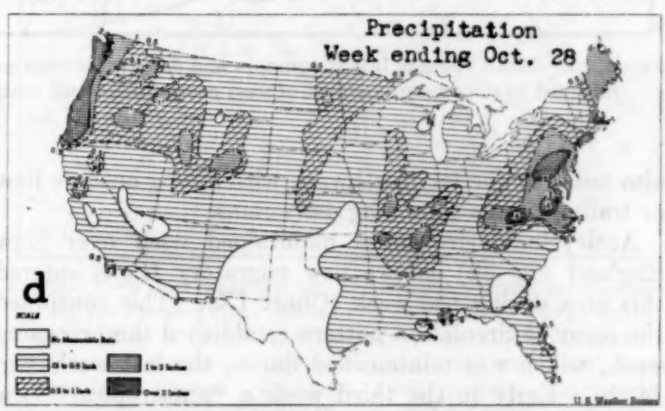


FIGURE 4.—(a) and (b) show an intensification of the new pattern which first emerged in figure 2. Fresh cold air from the north Pacific was swept through the trough to the Divide (c) as precipitation spread eastward. Note rain-shadow over much of drought area (d), with precipitation in Mississippi Valley in region removed from foehn components (a).

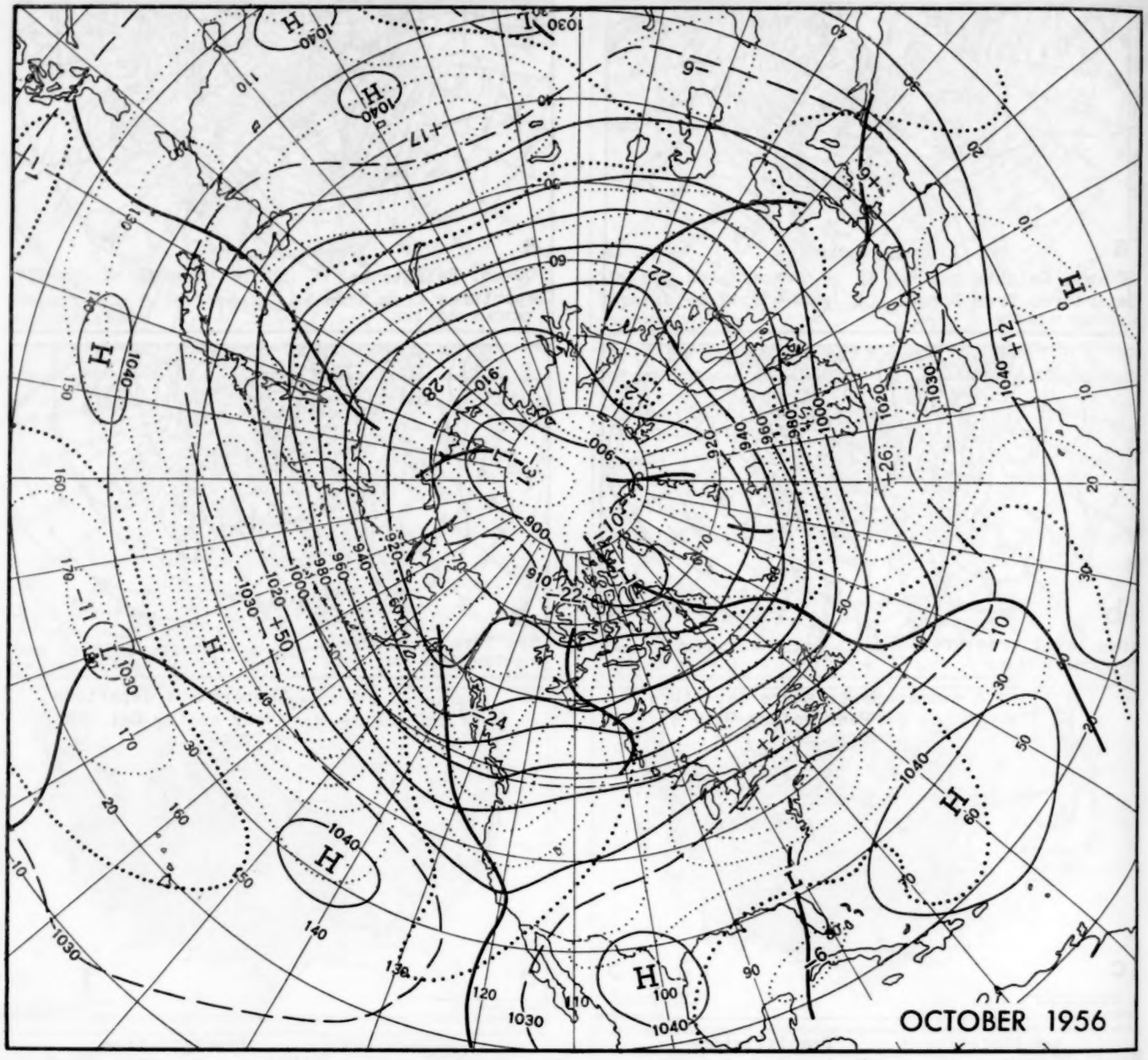


FIGURE 5.—Mean 700-mb. height contours and departures from normal (both in tens of feet) for October 2–31, 1956. Abnormal Pacific ridge led to strong development of west coast trough and complete suppression of east coast trough activity except in Florida.

also noted in the far Northwest, with strong onshore flow or trailing fronts providing daily rains.

Anticyclonic circulation maintained itself over New England (fig. 3b) as two new migratory Highs entered this area during the week (Chart IX). This continued the regional circulation pattern established the preceding week, which was reintensified during the last week (fig. 4a, b). Early in the third week a "semitropical" Low formed near Cuba in the easterlies well south of the High over New England. The Low moved up along the Florida coast and turned abruptly eastward only after reaching Chesapeake Bay on the 18th (Chart X). This turn was achieved during a momentary relaxation of the New England blocking as a fresh cold surge moved in. The storm left two or more inches of precipitation along most of the coast from Florida to southern New Jersey. St. Cloud, Fla., reported 17.30 in.

Temperatures were generally warm during this third week. An influx of marine air accompanying the storm noted above and rapid passage of Highs off the coast restored above normal conditions to most of the East (fig. 3c). In the West, the major trough was off the coast, and Pacific air from a more southerly and warmer source moderated previously cool conditions.

Fourth week.—During this period a return to, and intensification of, the general circulation type of the second week was noted. The west coast trough and New England High became stronger than before (fig. 4a and b). This was part of a general increase in amplitude of the mid-latitude wave system (fig. 4a) and a marked decline in zonal westerlies from what had been a typical October high index.

Below normal temperatures again dominated the West (fig. 4c), as the eastern Pacific trough came eastward and great quantities of cold North Pacific air were swept inland. Precipitation (fig. 4d) extended from the Mexican to the Canadian border in the West, with greatest amounts in the Northwest, where heights were below normal and cyclonic activity most marked. Again precipitation spread eastward as westerly perturbations were propagated downstream. A prelude to winter could be seen in the storm of the 23d to 24th which left up to 2 feet of snow in the northern Cascades; 19 inches at Alta, Utah; lesser amounts over Colorado and Wyoming; and 6 inches over the Black Hills of South Dakota.[2] As the cold air advanced eastward, precipitation also fell over the Northern and Eastern Plains, but foehn action extended the rain shadow of the Rockies over most of Texas.

The eastern half of the country was warm since the two daily Highs affecting the area were mainly of modified Pacific air (Chart IX). Precipitation in the East was associated with cyclonic developments in the east coast trough and orographic control of the strong onshore moist flow.

In the last few days of October (not shown here) another westerly disturbance worked eastward at lower latitudes from the west coast trough. Modest but significant amounts of precipitation fell over much of the drought area.

Thus October brought temporary relief to many critical drought areas. The further restoration of soil moisture and adequate water tables remained to the future.

2. MEAN CIRCULATION OF THE MONTH

From the preceding rather thorough sampling of the month one should be able to estimate the monthly mean state without great difficulty. Figure 5 shows the mean 700-mb. circulation pattern and accompanying height departures from normal. The westerlies were stronger and farther north than normal with essentially four mid-latitude troughs—not counting a weak lee-trough east of the Canadian Divide. In the Pacific, an anomalously long wavelength existed; the troughs were on either shore, separated by an elongated ridge. Across the northern periphery of the ridge lay a strong, fast westerly belt, while in the ridge itself heights were 500 ft. above normal. This is the greatest positive (hemispheric) anomaly of record for October.

[2] See adjacent article by Vore and McCarter discussing forecasting problems associated with this type of development.

In retrospect one can see that the first week of October (fig. 1a) was essentially a continuation of the regime which prevailed during September [3]; i. e., an east coast trough and a ridge west of the Divide. Only in the second week of October, as the west coast trough deepened and anticyclogenesis prevailed over the East (fig. 2), did the new regime become manifest. During the last two weeks secondary variations of the new pattern prevailed. Consequently, there was a considerable change in circulation type over North America between September and October and, as we have seen, a significant change in certain aspects of the precipitation distribution. An exception to the general change, however, should be noted in the low-latitude trough over Florida which represented little variation in circulation or weather for this area. For the country as a whole, temperature changes were greater than average; i. e., 58 percent of the stations changed temperature by more than one class [3] compared to 35 percent normally anticipating so great a change from September to October.

Another interesting facet of October's weather has been pointed out by Ballenzweig. In recent research on hurricanes [1], he has established that patterns similar to figure 5 are generally favorable to hurricane development and subsequent incidence in the Florida area. How then does one account for only one "semitropical" Low this October? His precursory survey of sea surface temperatures as plotted on current weather maps was expanded and is presented in figure 6. Although complete data are not yet available, those so far examined show surface water temperatures this October were below normal [10] and almost all boxes were below 81°–83° F., which Palmén has noted as approximately the lowest water temperature over which hurricanes are likely to form [12]. Just how

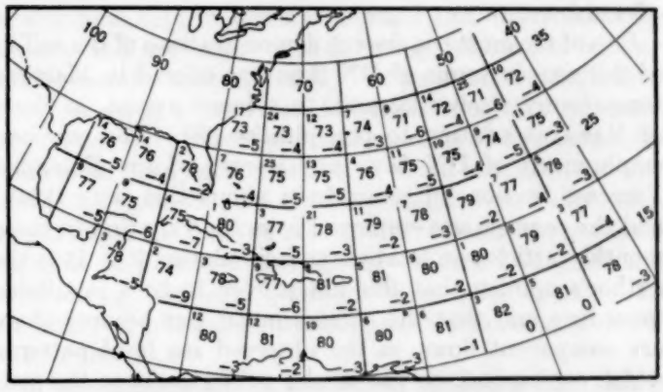


FIGURE 6.—Preliminary survey of sea surface water temperatures (°F.) for October from plotted synoptic data on eleven selected days. Key: in upper left corner of square, number of observations; center, mean sea surface temperature; lower right, departure from normal. Data far from complete but strongly suggest prevalence of cooler than normal conditions.

[3] Monthly temperature classes are defined with reference to the monthly variability and normal temperature for each station. Limiting departures are determined from past records so that classes below, near, and above normal each occur ⅓ of the time, while much below and much above occur ⅙ of the time.

successfully these anomalies can be related to the atmospheric circulations of preceding months is beyond the scope of this note. However, both August and September were conspicuous for strong westerly trough activity in western and eastern sectors of the Atlantic. In fact, the discussion of September [3] mentioned the unconfirmed report of an ice floe sighted near the Azores in uncommon southerly latitudes. Since water temperature anomalies are usually assumed to change but slowly, there is here a definite suggestion (cf. Riehl [14]) that such anomalies have prognostic implications. For a month with similar regional circulation characteristics, but with hurricane activity, the reader is referred to October 1947 [4]. It should also be mentioned that the Low near Cuba (Chart X) on the 30th and 31st became a full-fledged hurricane on November 4.

3. MEAN HEIGHT DEPARTURES FROM NORMAL AND WEATHER ANOMALIES

In the course of this series of articles considerable attention has been paid to the relation between surface weather and mean 700-mb. height anomalies. The usual procedure is to interpret the height anomaly gradients by means of the geostrophic relationship and to speak of "anomalous components" of flow. This departure from normal (DN) flow may be considered as that flow which, when added to the appropriate normal flow, would yield the observed flow pattern. Relating mean states of temperature and precipitation to the observed mean 700-mb. flow pattern is rendered much easier through explanations couched in terms of the DN flow, as if the flow has direct physical existence. The general success of this approach has won it a certain degree of acceptance, but no explicit justification of its employment has been attempted. It is therefore proposed that some further rationalization be offered here.

One of the most convincing demonstrations of the utility of thinking in terms of DN flow was offered in Martin's temperature studies [8] and, to a lesser extent, in those of Hawkins relating to precipitation [8]. The common employment of DN flow in the work of the Extended Forecast Section [9] stems from about this time (1949) and the concept was employed from the very first in these monthly articles on weather and circulation [6]. It is the author's opinion that this has proven to be a justifiable procedure and that the success noted was because there are component flows on the observed sea level patterns which correspond, on the whole, quite closely to the concomitant 700-mb. height departure from normal (DN) patterns. This might be extended to the effect that, strong gradients of 700-mb. DN flow usually resemble the total observed flow at sea level. Where the DN flows are weak, and over continental areas in general, this correspondence becomes less well marked. In view of the fact that we are concerned with mean maps, and that cold Lows and warm Highs are the more stable and longer-lived elements

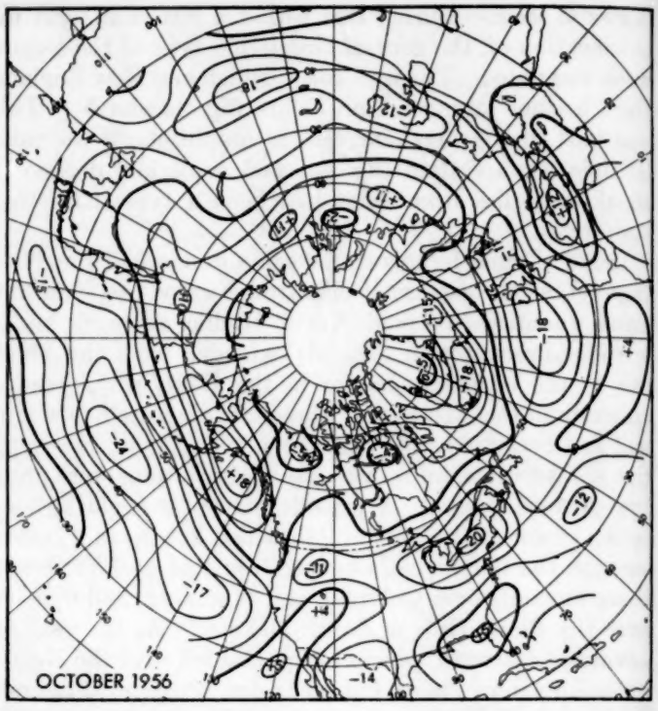


FIGURE 7.—Vertical component of mean relative geostrophic vorticity at 700 mb. for October 2–31, 1956. Centers are labeled in units of 10^{-6} per second, negative-anticyclonic, positive-cyclonic. Compare overall field with height departures from normal (fig. 5), and sea level mean pressure (fig. 8).

contributing to these means, the total resemblance essentially reaffirms the hydrostatic equation if one admits the persistent recurrence of given circulation states. On the other hand, shallow Highs and Lows are subject to steering by the upper-level currents. These upper currents are then generally indicative of the deployment of this class of sea level systems.

In this latter connection previous work related the tracks of daily sea level cyclones and anticyclones to the relative vorticity field at 700 mb. [5, 13]. The relation between height anomalies and relative vorticity is quite straightforward, since the anomaly centers are, in effect, the perturbations superposed upon a normal field of almost straight westerly flow. If one compares the departures from normal in height (fig. 5) with the 700-mb. field of relative vorticity (fig. 7) the general similarity is quite evident. Correspondence of significant centers was excellent. For example, major positive anomaly centers in the Pacific, St. Lawrence Valley, eastern Atlantic, and southern Siberia found direct reflection in the anticyclonic (negative) vorticity centers; in like manner, the stronger negative height centers in the Gulf of Alaska, off southeastern Greenland, over European Russia, and in northeastern Siberia had cyclonic relative vorticity centers associated with them. The correlation coefficient between 700-mb. height departure from normal pattern (fig. 5) and the 700-mb. field of relative vorticity (fig. 7) was computed

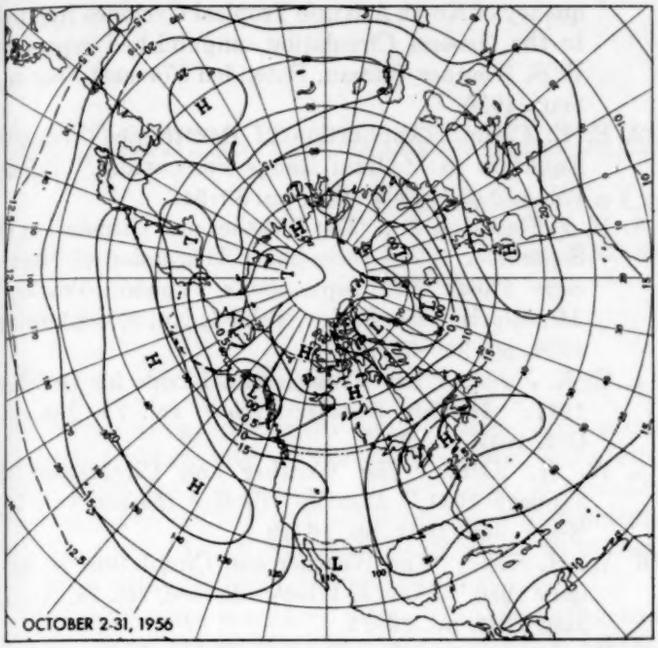


FIGURE 8.—Thirty-day mean sea level pressure, October 2–31, 1956. Strong High over New England resulted in onshore moist currents over most of east coast and warm return flow in central United States. Strong Gulf of Alaska Low was accompanied by weak Basin ridge and anomalous cyclonic activity along west coast of North America.

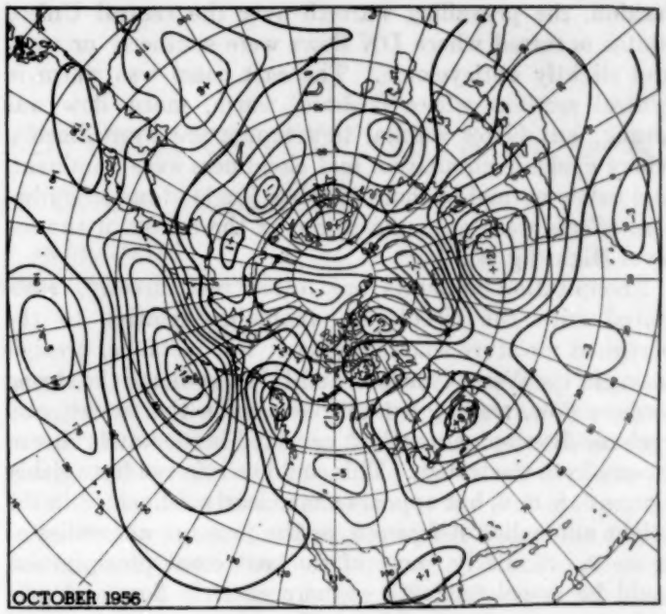


FIGURE 9.—Mean sea level pressure departure from normal for October 2–31, 1956. Note similarity in field of departures to height departure field (fig. 5), also correspondence of strong gradients with sea level gradients (fig. 8).

at 72 points distributed evenly around the hemisphere between 30° and 60° N., inclusive, and was found to be −0.70.

Actually, the relative vorticity field at 700 mb. can also be directly related to the field of total sea level pressure. This connection may be found in earlier articles (e. g., Klein [5]) but a forthright statement of the relation has been lacking. Presumably through the agency of the hydrostatic equation, well-marked centers of vorticity (fig. 7) can usually be related to similar centers at sea level (fig. 8). The correlation between the patterns of figures 7 and 8 on the 72-point grid was found to be −0.74. This was larger in magnitude than the correlation between 700-mb. height departures from normal and the mean sea level pressure pattern, which was 0.63 for an 81-point grid (including data at 75° N.). Thus the 700-mb. height departures from normal are closely related to the field of relative vorticity (at 700 mb.) and, to a slightly lesser degree, to the sea level pressure field itself.

Of greater relevance to the general problem is the relation between the upper-level height departures from normal (fig. 5) and the sea level departures from normal (fig. 9). Inspection reveals that, although the maps were not identical, overall similarity was striking. The correlation coefficient between the two patterns, computed at 81 points distributed evenly around the hemisphere between 30° and 75° N., was 0.82. This demonstrates the desired relationship since the prime requisite is that the anomalous, or abnormal, sea level flow be closely related to the 700-mb. height DN flow. In essence this infers that the immediate causes of the mean temperature and (to a lesser extent) precipitation departures from the climatic average are abnormal components of flow in the lower troposphere.

The general mode of thinking outlined above is far from new but explict demonstrations have been seldom offered. Nonetheless, objections to the use of any departure from normal map as depicting a real physical entity are commonly met. More recently the mathematical expression of any flow field in terms of normal and abnormal components and the utility of such representation has become more generally appreciated [2]. In practice, one finds few, if any, cases in which mean DN flows of significant intensity do not have actual physical currents of like nature on some of the daily synoptic charts which contribute to the series. Comparisons can also be made between 5-day mean height departures at 700 mb. and the concurrent sea level patterns in figures 1 through 4. Where DN gradients were strong, sea level gradients were quite similar. In a number of instances surprising correspondence of detail can be noted.

In application then, one would associate the below normal temperatures in the West (Chart I-B) with the abnormally strong fetch of cold air from the northeastern Pacific into the western United States, indicated by the departure from normal flows at 700 mb. (fig. 5) and at sea level (fig. 9). The same deductions are possible from the total observed sea level pattern (fig. 8) although only comparison with the normal (i. e., fig. 9) or an analog will reveal the inherent abnormality in figure 8. In like

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fashion, the prevailing warmth over the central United States occurred where DN flows were southerly or weak and slightly anticyclonic. The east coast was warm in central sections where onshore, warm, moist flow was strong, but below normal in temperature over Florida, where cyclonic circulation and cloudiness were dominant, and below normal in southern New England, where radiation effects were at a maximum at the center of the sea level High (fig. 8).

Precipitation amounts are (often less directly) associated with the circulation anomalies relative to the pertinent moisture source regions. For instance, precipitation in the West (Charts II and III) was due to the strong onshore flow, trailing frontal passages in the trough, and cyclonic developments which occurred immediately downstream from the trough. This could be inferred from either figures 5, 8, or 9, but appears more clearly delineated in the height anomalies of figure 5, or the pressure anomalies of figure 9. Similarly, most of the east coast precipitation could be associated with onshore easterly flow and perturbations associated with it. Heaviest amounts occurred in the central sector, where onshore flow was strongest, and over Florida where cyclonic circulation, at sea level and aloft, was most marked. Precipitation totals in the central portion of the country were comparatively small and, in proportion, less directly related. The precipitation was released by perturbations travelling downstream from the west coast trough, with moisture supplied from the Gulf of Mexico and advected northward around the ridge in the East.

The general utility of concentrating attention upon abnormal flow features to explain anomalies in weather has been pointed out in many and diverse writings. The application of this concept to mean flows is both logical and demonstrable. However, it must be expected that, when time means are used, best results will be obtained when dealing with meteorological elements which are continuous in nature and appropriate to time averaging; i. e., temperature, humidity, etc. A discontinuous element such as precipitation does not lend itself as readily to such treatment, although Stidd's work [15] seems to indicate that when longer and longer time means are employed. even these elements can be successfully treated. The trend of modern meteorology is definitely toward the prediction of circulation states, although exceptions may be noted. The value of using the departure from normal concept in interpreting these states in terms of weather is believed to be both sound and useful. Furthermore, it is possible that one of the more promising available attacks on the problem of long-range forecasting lies in the treatment of evolution of circulations primarily through consideration of the field of height anomaly [7].

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PROGNOSTIC PROBLEMS ASSOCIATED WITH CUTOFF NEVADA LOWS

As Illustrated by the Case of October 23–24, 1956

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1. INTRODUCTION

This paper in general briefly discusses upper-level cutoff Lows that plunge into the Nevada area from the northwest during the fall months. In particular, it discusses the "explosive" surface and higher-altitude developments that occurred over North America between 0630 GMT, October 23 and 1230 GMT, October 24, 1956.

The presentation is confined primarily to the surface and 500-mb. levels and auxiliary charts, and all specific meteorological values or changes are for the 500-mb. level unless otherwise stated. Since surface tendencies and patterns at any given time almost entirely fail to foretell the depth and flow pattern around a deep developing Nevada storm 24 to 30 hours ahead, it is necessary to examine the upper flow and thermal field very closely to get an insight into the course of nature for the next day or so.

Whenever a vorticity cell at 500 mb. appears off the west coast of Canada or northwestern United States, the prognostic analyst is faced with the decision of either leaving the cell quasi-stationary in the same general area, or, in most cases, moving the center in one of the general directions of north, east, or south. When the current contours and isotherms up and down stream can be analyzed accurately, when the vorticity centers and ridges are well defined and conveniently spaced in a meridional flow pattern, and when the systems are moving uniformly the future direction of an impulse can usually be determined by subjective methods. Determining the rate of movement is more difficult. However, when there is strong zonal flow in which there are numerous minor impulses, the correct pattern at verification time is very elusive, especially if a big change in the zonal index occurs. The National Weather Analysis Center's (NWAC) prognostic analysts find that the Joint Numerical Weather Prediction Unit's (JNWP) numerical prognoses of the 500-mb. level have been very helpful in many situations where the index changes, where blocks develop or weaken, and where rate and direction of movement of systems are obscured to subjective methods.

Several plunging 500-mb. Lows complicated the weather picture during October 1956. During the first 3 or 4 days of the month a relatively weak quasi-stationary cutoff Low at 500 mb. was centered off the southern California coast. On the 4th and 5th a marked deepening occurred at more southerly latitudes near longitude 160° W., which caused the weak coastal impulse to move slowly eastward giving 0.50 to .70 inch of rain in the Santa Maria area. Twenty-four hour amounts of one to one and one-quarter inches were recorded at Bakersfield and Susanville on the 7th and 8th, respectively, associated with the movement of the closed Low into central Nevada by 1500 GMT, October 8.

In the meantime the deepening trough over the eastern Pacific had moved eastward and by 1500 GMT on the 8th an intense vorticity center with a closed 17,600-foot contour was centered 2° or 3° east of Ship Papa (50° N., 145° W.). By 0300 GMT on the 10th a deep trough had developed southward near latitude 170° W., and a sharp ridge was just west of Ship Papa, warming that station from −20° C. to −12° C. in 36 hours. Strong warm air advection toward Yakutat, Alaska, which warmed 10° C. in 12 hours, was maintaining the ridge between the two impulses. Thus at 0300 GMT on the 10th, the vorticity center about 5° longitude off Tatoosh was expected to move southeast. The speed of movement was very difficult to determine by subjective methods. There was no deep surface development with this situation but 24-hour rainfall amounts measured over an inch in southwestern and south-central Oregon.

Another good example of a plunging vorticity center is illustrated by the events occurring between 0300 GMT on the 26th and 1500 GMT on the 27th. A deep 500-mb. Low with a central height of 17,200 feet and temperature of −35° C. was centered near 51° N., 135° W. A sharp short-wave ridge to its west showed an 18,000-foot height value 25° longitude directly west of the cold Low and a 17,500-foot height at Barter Island. Any further building of heights to the north was halted due to very strong cold advection into the west side of the ridge and rapidly falling surface pressure already under the ridge, tending to tilt its axis northeastward toward Annette Island. In this case straight extrapolation of the cell of maximum cyclonic vorticity on the 500-mb. chart for 0300 GMT on the 25th would have placed the closed Low within 1° or 2° of the observed position on the chart for 1500 GMT on the 27th. The further history of this cell became very complicated and will not be discussed in this article.

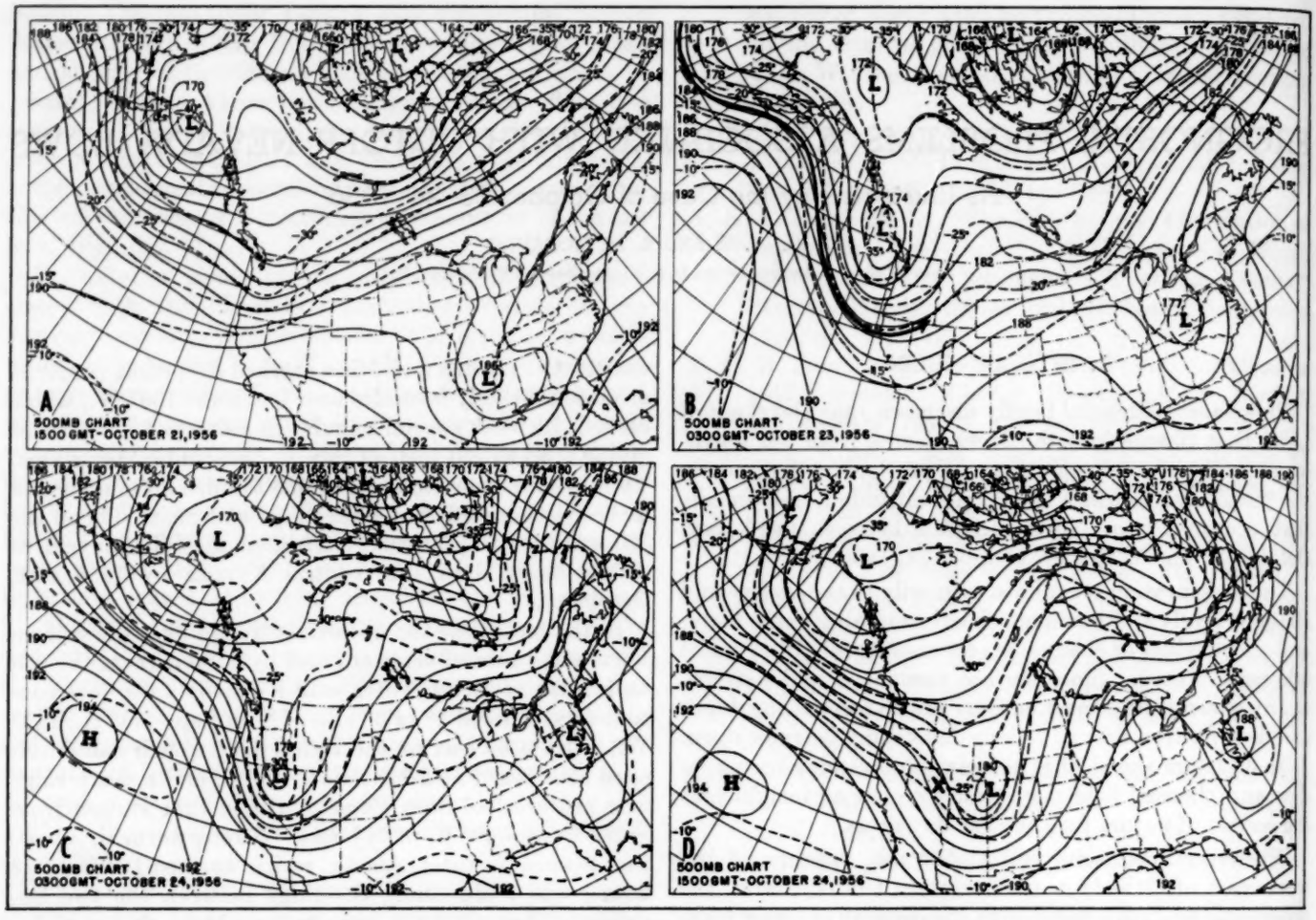

FIGURE 1.—500-mb. charts. (A) 36 hours before prognosis or 1500 GMT, October 21, 1956, (B) at forecast time or 0300 GMT, October 23, 1956, (C) 12 hours before verification or 0300 GMT, October 24, 1956, and (D) verification time or 1500 GMT, October 24, 1956. Extrapolated 36-hour position of the Low marked with an "X" on (D).

2. SUBJECTIVE PROGNOSIS OF THE NEVADA STORM OF OCTOBER 23–24

The primary topic to be discussed in this paper concerns the cold Low that plunged into the Nevada-Utah area during the period from 0300 GMT on the 23d to 1230 GMT on the 24th of October. This particular storm was chosen for study for the following reasons:

1. In retrospect, because the diagnosis of both its speed and depth by subjective means was more obvious compared to similar storms, it can be discussed with a reasonable amount of certainty.

2. The 30-hour surface prognostic chart prepared by one of the authors indicated the rather intense surface development, but placed the center much too far east.

3. The key to the rather "explosive" developments that occurred throughout the United States and Canada was the southeastward plunge of this cold Low.

Let us consider the subjective means that could be used to determine where to place the closed 500-mb. Low 36 hours after the time of prognosis. At 1500 GMT on the 21st (fig. 1A) the center under consideration was near 59° N., 149° W. with central height of 16,800 feet and temperature of −41° C. A significant vorticity maximum in the Oregon-Idaho area was destined to move rapidly east-northeastward, being controlled by the deep vortex over the Alaskan Gulf and the strong west-southwest flow south of the rather broad but potent cyclonic vorticity field west of the Hudson Bay area.

Thirty-six hours later at 0300 GMT on the 23d (fig. 1B), or at the time the forecast was made, the Alaskan Gulf Low had moved to the area of Port Hardy, British Columbia, with a central height of about 17,000 feet and temperature of −36° C. During the same period, the impulse from the Idaho area moved rapidly to Lake Superior and was associated with a weak surface Low south of Moosonee, Ontario. The very potent cyclonic vorticity maximum remained poised in the Churchill, Manitoba area. By examination of the contours and isotherms in figure 1B, and on the assumption that the Port Hardy Low would move eastward, little ridging could be expected to occur west of Hudson Bay to advect the vorticity south-

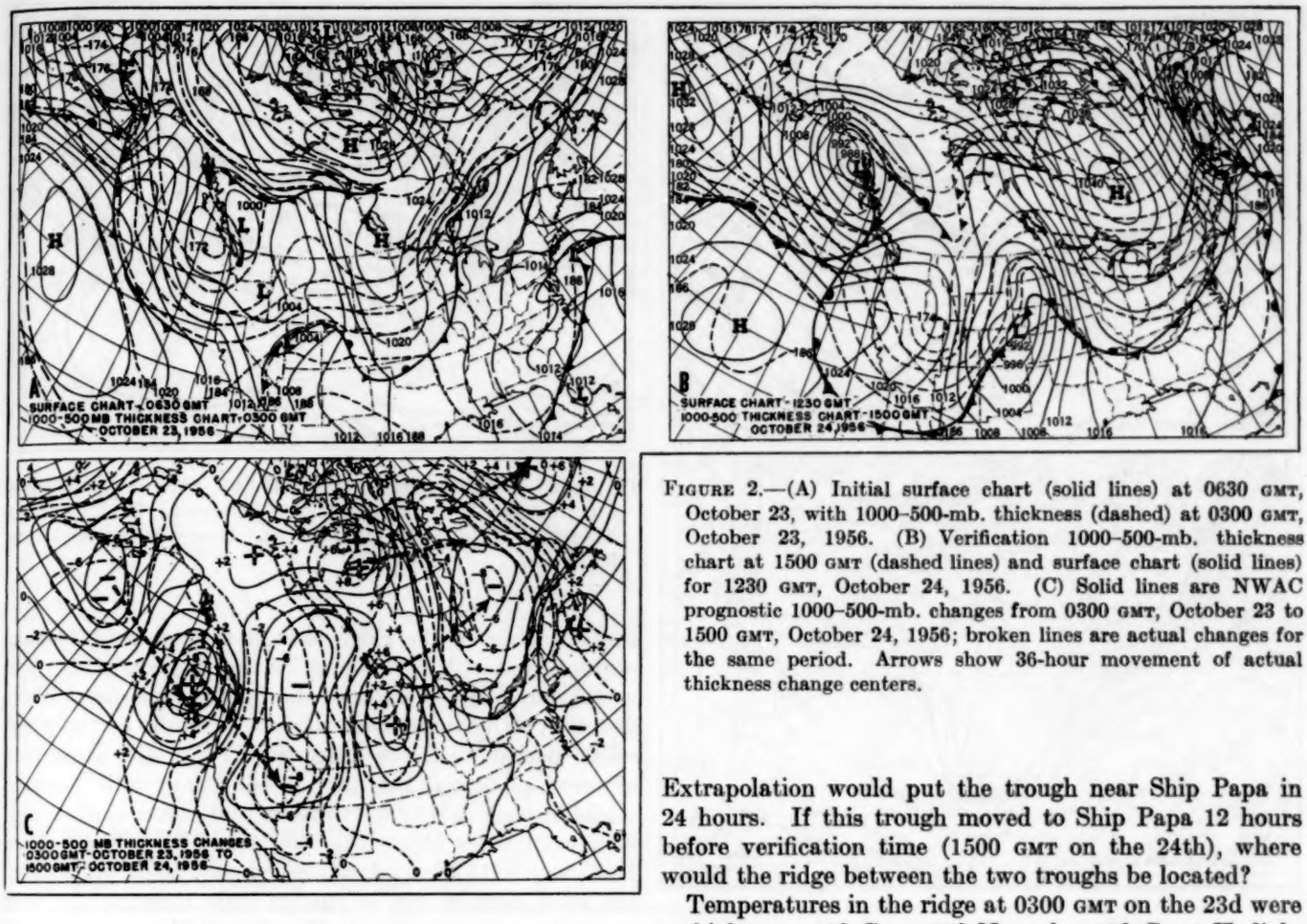

FIGURE 2.—(A) Initial surface chart (solid lines) at 0630 GMT, October 23, with 1000–500-mb. thickness (dashed) at 0300 GMT, October 23, 1956. (B) Verification 1000–500-mb. thickness chart at 1500 GMT (dashed lines) and surface chart (solid lines) for 1230 GMT, October 24, 1956. (C) Solid lines are NWAC prognostic 1000–500-mb. changes from 0300 GMT, October 23 to 1500 GMT, October 24, 1956; broken lines are actual changes for the same period. Arrows show 36-hour movement of actual thickness change centers.

eastward and deepen the Moosonee surface Low. However by the plunging of the 500-mb. Low and attendent cyclonic vorticity into the Salt Lake City area in 36 hours, the comparatively warm air (−14° C.) in the Ely area would be advected rapidly to the northeast, building a major ridge which in turn could advect the very potent cyclonic vorticity near Churchill to the southeast and produce intense surface deepening over the Canadian Atlantic coast.

From the positions shown by figures 1A and 1B, straight 36 hour extrapolation would have placed the 500-mb. low center near Elko, Nev., at verification time or 7° of longitude too far west as shown in figure 1D. Using this point as a tentative 36-hour prognostic position, let us explore the existing upper-air environment of the center at Port Hardy and attempt to find reasons for moving or not moving the extrapolated center. A quasi-stationary cold Low in the central Pacific, together with a well-defined short-wave trough of moderate amplitude that had moved into the Adak area, had already built a strong ridge at 155° W. Heights in the ridge were 19,200 feet at 45° N. and 17,400 feet 15° of latitude to the north giving a very strong jet with winds well over 100 knots as shown in figure 1B. Twelve hours prior to 0300 GMT on the 23d, the trough at Adak had moved roughly 12° of longitude. Extrapolation would put the trough near Ship Papa in 24 hours. If this trough moved to Ship Papa 12 hours before verification time (1500 GMT on the 24th), where would the ridge between the two troughs be located?

Temperatures in the ridge at 0300 GMT on the 23d were as high as −16° C. at 55° N. and −19° C. at Kodiak. Strong warm advection, as shown in figure 1B, was directed toward a point 5° or 6° west of Port Hardy. However, with the eastward propagation of the ridge ahead of the trough moving from Adak, it would be reasonable to assume that in 24 hours the warming would be greatest farther east or in the Port Hardy-Tatoosh area. Thus the offshore picture after 24 hours would be an intense cyclonic vorticity area near Ship Papa and also located north or north-northeast of the strong ridge that had developed 24 hours earlier. Continuing southerly circulation around the quasi-stationary cold Low in the central Pacific would tend to build heights even more to the south of Ship Papa. Thus height falls to the north and rises to the south would result in an intensifying vorticity field near Ship Papa. It should be mentioned here that neither was there any apparent deepening over the southern latitudes in the Ship Victor (31° N., 164° E.) area to move the cold mid-Pacific Low, nor was there any building high-amplitude ridge to the rear of the trough at Adak to produce enough deepening to "pick up" the closed Low and move it with the short wave. Along with the vorticity at Ship Papa there would be a sharp ridge of relatively warm air from the parent ridge in the Pacific and extending to the northeast toward the area evacuated by the plunging 500-mb. Low.

409153—57——3

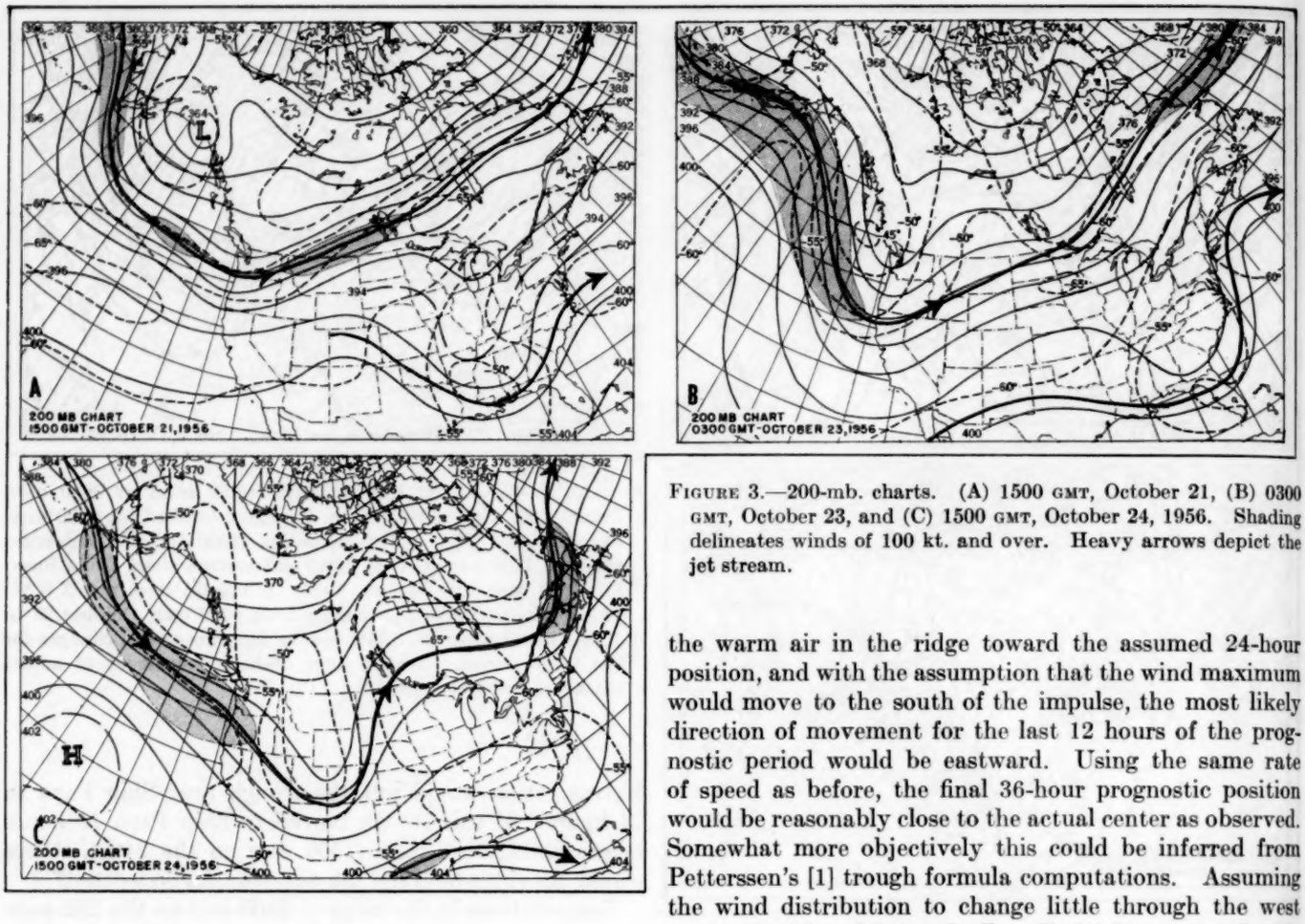

FIGURE 3.—200-mb. charts. (A) 1500 GMT, October 21, (B) 0300 GMT, October 23, and (C) 1500 GMT, October 24, 1956. Shading delineates winds of 100 kt. and over. Heavy arrows depict the jet stream.

The history of the movement and development of the trough and ridges discussed in the last two paragraphs, and the relative positions of the systems in figure 1B, suggest that a very reasonable path open to the Port Hardy Low, at least for the first 24 hours, would be along the line of proposed extrapolation. Twenty-four-hour trajectories would show a deepening trough inland over the Pacific Coast States. Since the warm air in the ridge could most easily be moved to the southeast as discussed before, there was little chance that a strong ridge could move in over southwestern Canada, thus plunging the Low due south or southwest. By pure extrapolation from the assumed offshore 24-hour prognosis, some of the intense cyclonic vorticity from the Ship Papa area would certainly be near the Washington coast 12 hours later at verification time. Allowing for some acceleration due to the rapid approach of the trough across the major ridge, 24-hour extrapolation would put the Low near southwestern Idaho. From the chart for 1500 GMT on the 22d, very careful extrapolation of the wind maximum along the jet would show the strongest winds to be inland and south of the assumed center. Thus at 0300 GMT on the 24th with the approach of the cyclonic vorticity to the Washington coast and the attendant propagation of the warm air in the ridge toward the assumed 24-hour position, and with the assumption that the wind maximum would move to the south of the impulse, the most likely direction of movement for the last 12 hours of the prognostic period would be eastward. Using the same rate of speed as before, the final 36-hour prognostic position would be reasonably close to the actual center as observed. Somewhat more objectively this could be inferred from Petterssen's [1] trough formula computations. Assuming the wind distribution to change little through the west coast trough, the gradually diminishing wavelength between this trough and the one upstream would require gradual acceleration of the speed of the first trough.

The 0300 GMT 500-mb. chart on the 23d showed falls of 700 feet in 36 hours in the Port Hardy area. Applying the same fall to the Grand Junction-Lander area would have given a very accurate estimation of heights around the center that verified 36 hours later.

Admittedly there has been an element of back-casting in the discussion so far. The authors are not aware of any computations or objective techniques that would determine the 36-hour movement of this type Low more accurately. Wilson's [2] grid method placed the center over northwestern Washington in 24 hours. Mean flow charts [3] prepared by NWAC moved the maximum vorticity associated with the Low to the east-northeast, and even the strictly objective JNWP thermotropic model moved the center to the east. Further discussion of the JNWP prognosis is made in section 4.

3. CHAIN REACTIONS DOWNSTREAM

In the remainder of the article, it will be accepted that the Low has moved to the position near Grand Junction as shown in figure 1D, and instead of discussing further prognosis, let us examine the rather dramatic changes

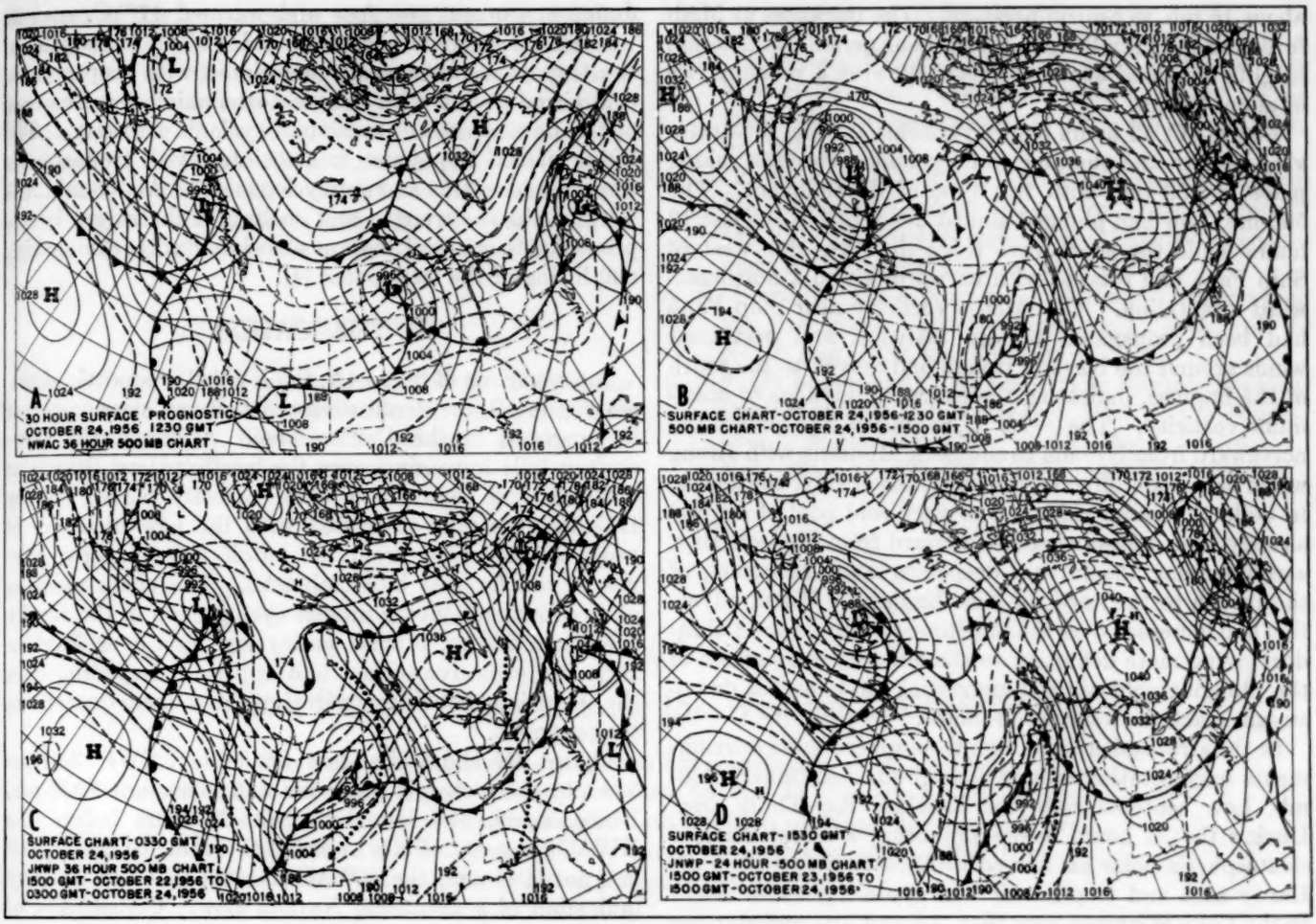

FIGURE 4.—(A) NWAC 30-hour surface (solid lines) and 36-hour 500-mb. (broken lines) prognostic charts verifying at 1230 GMT and 1500 GMT, October 24, 1956, respectively. (B) Actual surface and 500-mb. charts for 1230 GMT and 1500 GMT, October 24. (C) Actual surface chart (solid lines) for 1230 GMT, October 24, with JNWP 36-hour thermotropic 500-mb. prognostic chart and attendant 1000-mb. centers (small H's and L's) and troughs (dotted lines) verifying at 0300 GMT, October 24, 1956. (D) Actual surface chart (solid lines) for 1230 GMT, October 24, with JNWP 24-hour 500-mb. prognostic chart and attendant 1000-mb. centers and troughs verifying at 1500 GMT, October 24, 1956.

that did occur over all the United States and Canada on October 23 and 24.

At prognosis time (0630 GMT on October 23), the surface chart (fig. 2A) showed a filling Low of 998 mb. centered over southwestern Canada and two rather complex low pressure systems, one near Boise and the other southwest of Salt Lake City. Twelve-hour pressure falls of 12–14 mb. covered most of Idaho, Oregon, southeastern Washington, and the western half of Montana. In figure 2A, an initial injection of low-level cooling, as shown by isobaric cutting of the 1000–500-mb. thickness lines over northern California, was giving weak pressure rises, but the strongest cyclonic curvature and cold advection were still 10°–15° of longitude off the coast. The very low thickness values off Tatoosh plunged southeastward with the upper-level vorticity, giving a decrease of approximately 800 feet of thickness in the Ely area (fig. 2C). Most of this cooling was moved eastward by the NWAC prognostication since the 36-hour 500-mb. prognostic chart failed to show the plunge of the Port Hardy Low The strong low-level warm advection, shown in figure 2A, from Cheyenne north to the Canadian border, plus the new injection of warm air at all levels from the Las Vegas area ahead of the plunging upper Low, increased thicknesses 600–800 feet from Fargo north to Baker Lake (see fig. 2C). The resultant building of the ridge propagated the cold air and cyclonic vorticity poised in the Churchill area at 0300 GMT on the 23d to the southeast, accompanying the explosive deepening of the complex surface Low located near Moosonee at 0630 GMT on the 23d, and also contributed to the northward movement and deepening of the Low south of Nantucket (fig. 2B).

The rises in surface pressure in the Moosonee area and along the central Pacific coast were also spectacular. A High of 1028 mb. centered in the Winnipeg area moved to southern Hudson Bay and intensified to 1044 mb. The thickness changed very little in the High but 500-mb. heights increased about 400 feet allowing an increase of

about 16 mb. in central pressure. The thickness at Medford changed very little in the 36-hour period but 500-mb. heights increased about 500 feet, allowing a pressure rise of about 20 mb.

Figure 1C, 12 hours before verification time, illustrates very clearly the thermal and dynamic processes taking place at 500 mb. with this type of development. The 500-mb. Low had plunged almost due south in the last 12 hours while the short-wave ridge that was due west of Ship Papa had rotated with its warm air to a northeastward orientation. The intense vorticity near Ship Papa had been propagated rapidly eastward and maximum winds around the Nevada trough had moved to the south of the impulse, indicating the eastward advance of maximum vorticity. The −15° C. isotherm had progressed northward from Nevada to southern Montana with strong warm advection directed toward Hudson Bay, continuing to build the major ridge. The very cold pool of air had already been advected southeastward from Hudson Bay, accompanying the further deepening and sharpening of the trough to the north of New England. Warm advection had increased over the Maritime Provinces and Labrador, giving more definition to the building ridge ahead of the plunging cold air and suggesting that further downstream reactions were yet to follow.

In the stratosphere and high troposphere these developments were rotating around a deep quasi-stationary 200-mb. Low centered near the Resolute Bay-Thule area. During the 36 hours before prognosis, a warm mass of stratospheric polar air moved southeastward to the Port Hardy area and tropical air was appearing as far north as the Lake Winnipeg area (figs. 3A and 3B) and starting to give definition to two distinct masses. As shown in figure 3C (the verification 200-mb. chart), the west coast mass of stratospheric air had plunged to the Great Falls-Grand Junction line and the next trough with its warm air had moved into the Alaskan Gulf. Cold tropical air had made little progress northward between the two systems as shown by the thermal pattern over Oregon and Washington; thus only a weakening ridge separated the two troughs, a condition favorable to eastward movement and weakening of the Rocky Mountain trough. A large area of −65° C. or colder air, as indicated by values at Churchill and International Falls, illustrates the magnitude of the northward thrust of tropical air over the building tropospheric ridge and surface High. The warm Hudson Bay pool of air had been propagated eastward and was well defined over northern Quebec.

The changes in height of the tropopause at the key stations of Port Hardy, Edmonton, Grand Junction, and Churchill were very significant during the 72-hour period from 1500 GMT on October 21 to 1500 GMT on October 24. During the 36 hours prior to prognosis time, the tropopause at Port Hardy sank 6,000 feet and warmed 10° C., at Edmonton it rose 11,000 feet and cooled 13° C., and at International Falls it lowered 6,000 feet and warmed 10° C. During the forecast period the tropopause at Grand Junction sank 12,000 feet and warmed 17° C. and at Churchill it rose 8,000 feet and cooled 9° C. Lowering of the tropopause is normally associated with tropospheric cold air advection with the greatest sinking near the core of the Low or area of maximum cyclonic vorticity. The lifting of the tropopause is associated with tropospheric warm air advection and anticyclogenesis. At 200 mb., the warming in the troughs and cooling in the ridges is due primarily to vertical motion associated with the sinking and lifting of the tropopause [4].

4. VERIFICATION

A comparison of figure 4A, the NWAC prognostic chart, and figure 4B, the verification chart, shows a serious error in prognosis in the Denver area. Although the large surface falls appearing over the northwestern States at 0630 GMT on October 23 were correctly moved to the Dakotas, the falls associated with the new injection of warm air stemming from the cutoff 500-mb. Low were moved too far east into Nebraska. The chain reaction of developments giving intense cyclogenesis in the Rocky Mountain States, intense anticyclogenesis over Hudson Bay, and explosive surface and upper-air deepening over the Maritime Provinces were indicated inadequately in the prognosis.

Figure 4C shows the last available JNWP 36-hour 500-mb. thermotropic prognosis and attendant 1000-mb. Highs, Lows, and troughs made 12 hours before the NWAC forecast. Fully aware of the value of the JNWP prognostic charts, the NWAC analyst failed to see any indication of a deepening Nevada Low. Comparison of the actual 0300 GMT surface chart and the JNWP prognosis shows obvious errors in the Grand Junction and Hudson Bay areas. Figure 4D is a copy of the numerical 24-hour 500-mb. thermotropic prognosis and attendant 1000-mb. centers and troughs made 12 hours after the NWAC forecast. Comparison with the actual 1500 GMT surface chart again indicates an error in the Denver area, but good verification in the James Bay area.

5. SPECIAL WEATHER PHENOMENA

On the 23d and 24th, strong winds occurred at the surface over a large area around the intense low center. Average wind speeds for this period as reported in the Local Climatological Data sheets were about double the monthly average for October at many stations from Nevada to Missouri and from Texas to the Dakotas. Severe duststorms were reported mainly in the warm sector of the Low. Precipitation with the Low was the first general precipitation over the Great Basin in several months. Amounts of ½ to over 1 inch occurred west of the Divide as far south as northern portions of California, Nevada, and Utah, and also in central Wyoming. Much of the precipitation was in the form of snow, particularly in the mountains. Snow also occurred in Colorado and northwestern Kansas. The strong cold northerly flow to

the west of the Low brought temperatures of well below freezing to many stations in the Great Basin and Rocky Mountains. On the morning of the 24th, first frosts of the season were reported at several California stations. By the morning of the 25th, below freezing temperatures were reported as far south as Arizona and New Mexico. The strong southerly flow east of the Low caused well above normal temperatures over the Mississippi River Valley, particularly over the upper Mississippi Valley.

ACKNOWLEDGMENTS

The authors wish to thank the staff of the Daily Map Unit for their excellent cooperation in the preparation of the illustrations. We are also indebted to the staff of NWAC for their helpful suggestions.

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2. H. P. Wilson, "A Test of a Grid Method of Forecasting the Motion of Lows at 500-mb. in Arctic Regions," *Cir.* 2539 TEC 194, Meteorological Division, Department of Transport, Canada, Oct. 4, 1954.
3. R. Fjørtoft, "On a Numerical Method of Integrating the Barotropic Vorticity Equation," *Tellus*, vol. 4, No. 3, Aug. 1952, pp. 179–194.
4. J. F. O'Connor, and C. R. Fean, "The Record-Breaking Cold Wave of Mid-November 1955 in the Northwest," *Monthly Weather Review*, vol. 83, No. 11, Nov. 1955, pp. 279–291. (See p. 288).

Water Supply Forecasts for the Western United States

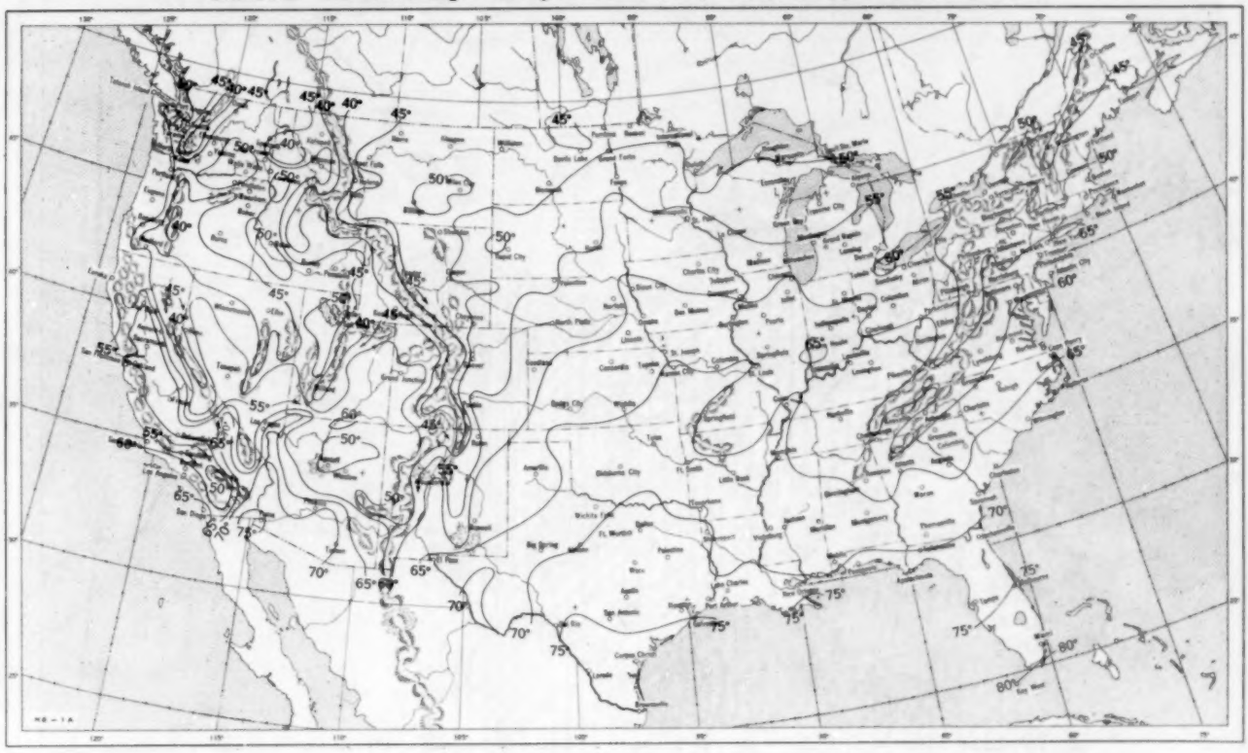
Published monthly from January to May, inclusive. Contains text, map, and tabulations of water supply forecasts for the 11 Western States, by the Weather Bureau and the California State Division of Water Resources. For copies of the 1957 forecasts apply to River Forecast Center, Weather Bureau Office, 712 Federal Office Building, Kansas City 6, Mo.

CORRECTION

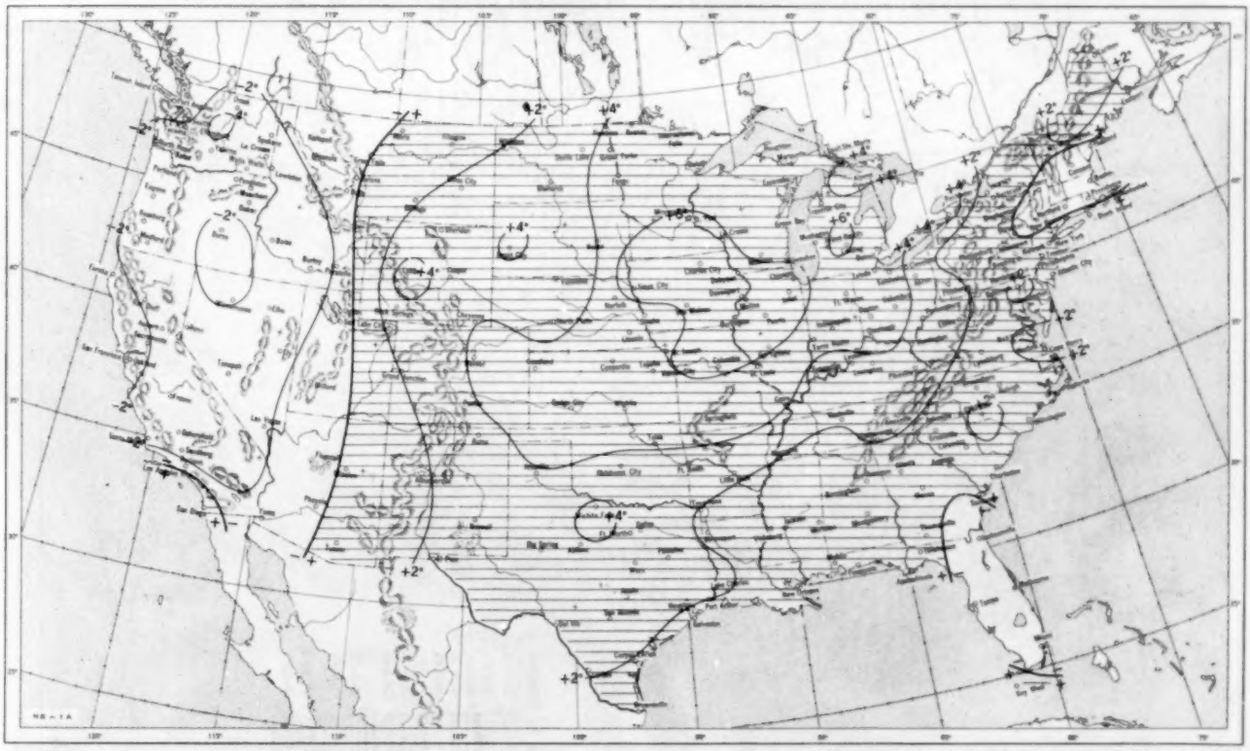
MONTHLY WEATHER REVIEW, vol. 84, No. 9, p. 333: In column 1 of Extension to the Standard Atmosphere the name of the National Advisory Committee for Aeronautics was unintentionally omitted from the list of participating agencies.

U. S. GOVERNMENT PRINTING OFFICE: 1957

Chart I. A. Average Temperature (°F.) at Surface, October 1956.

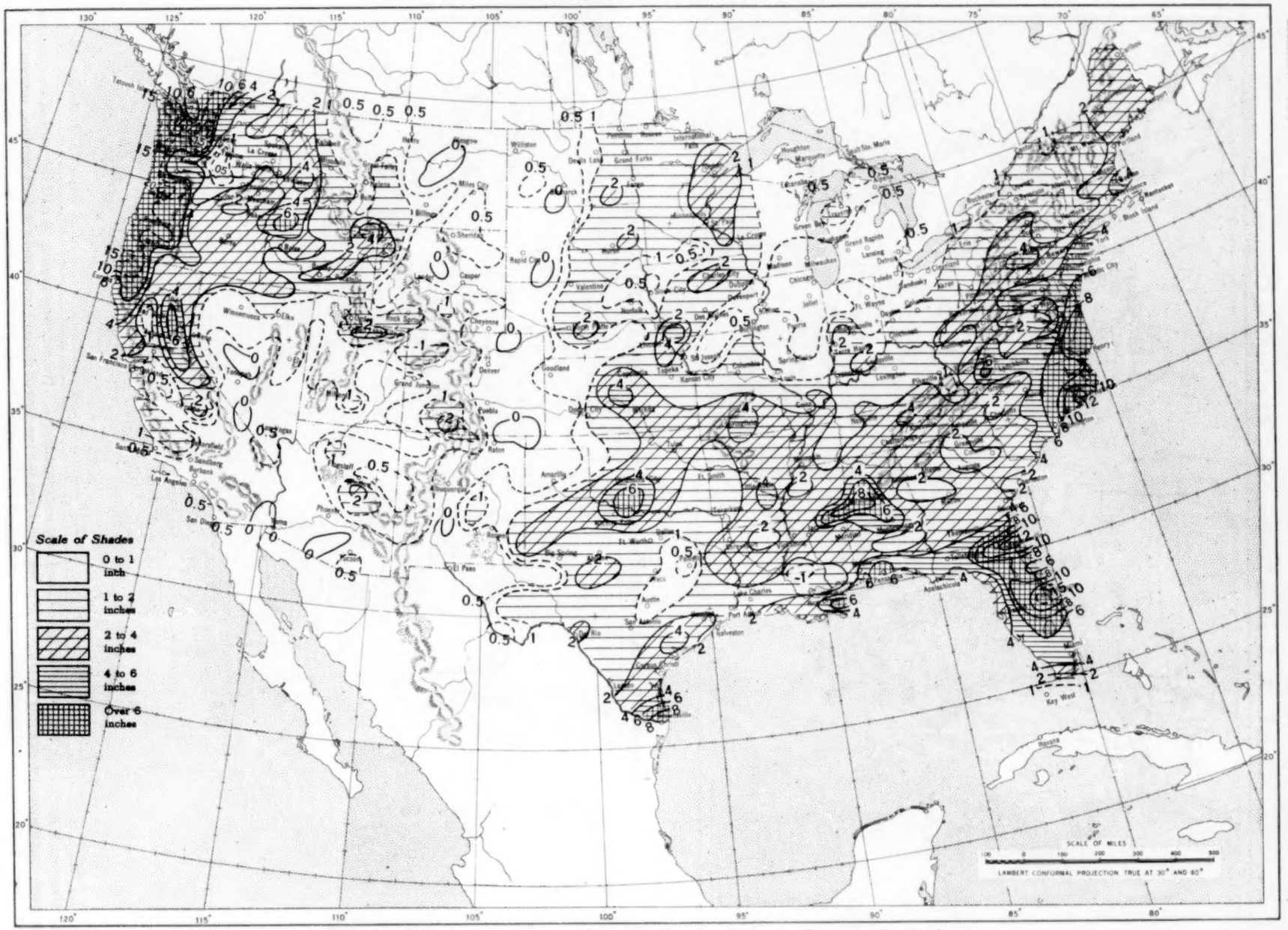


B. Departure of Average Temperature from Normal (°F.), October 1956.



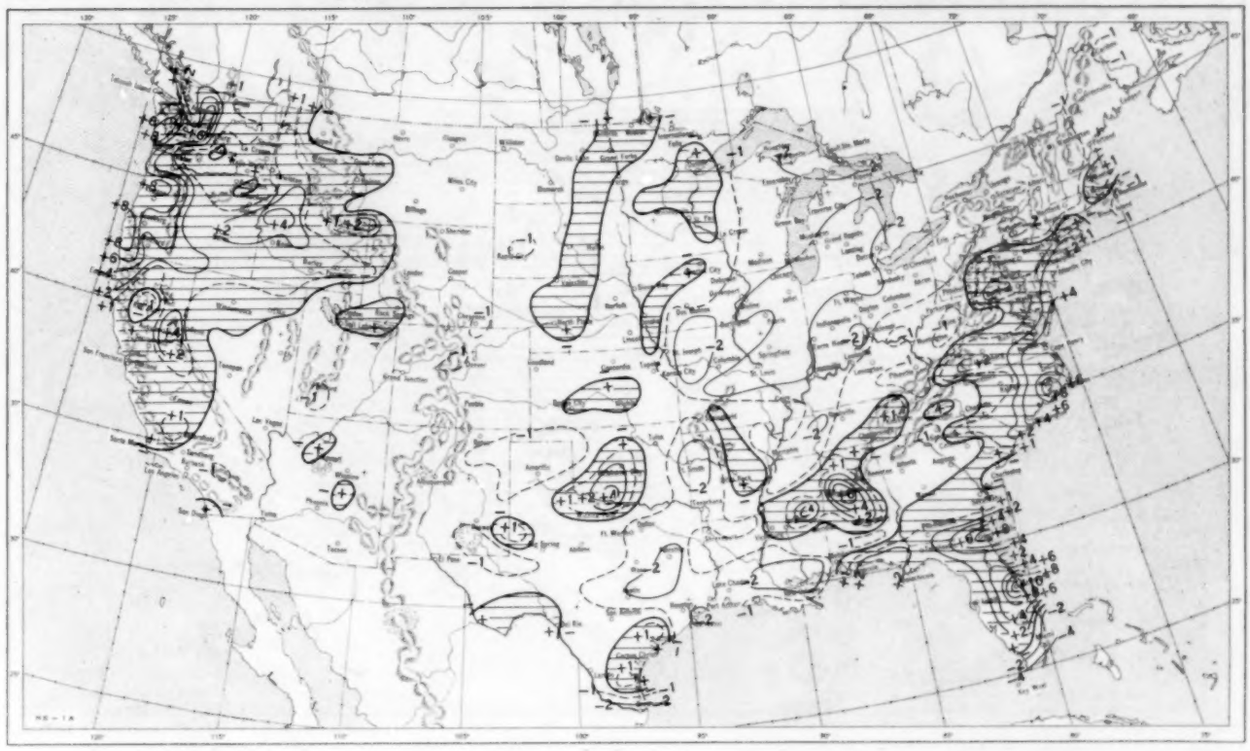
A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), October 1956.

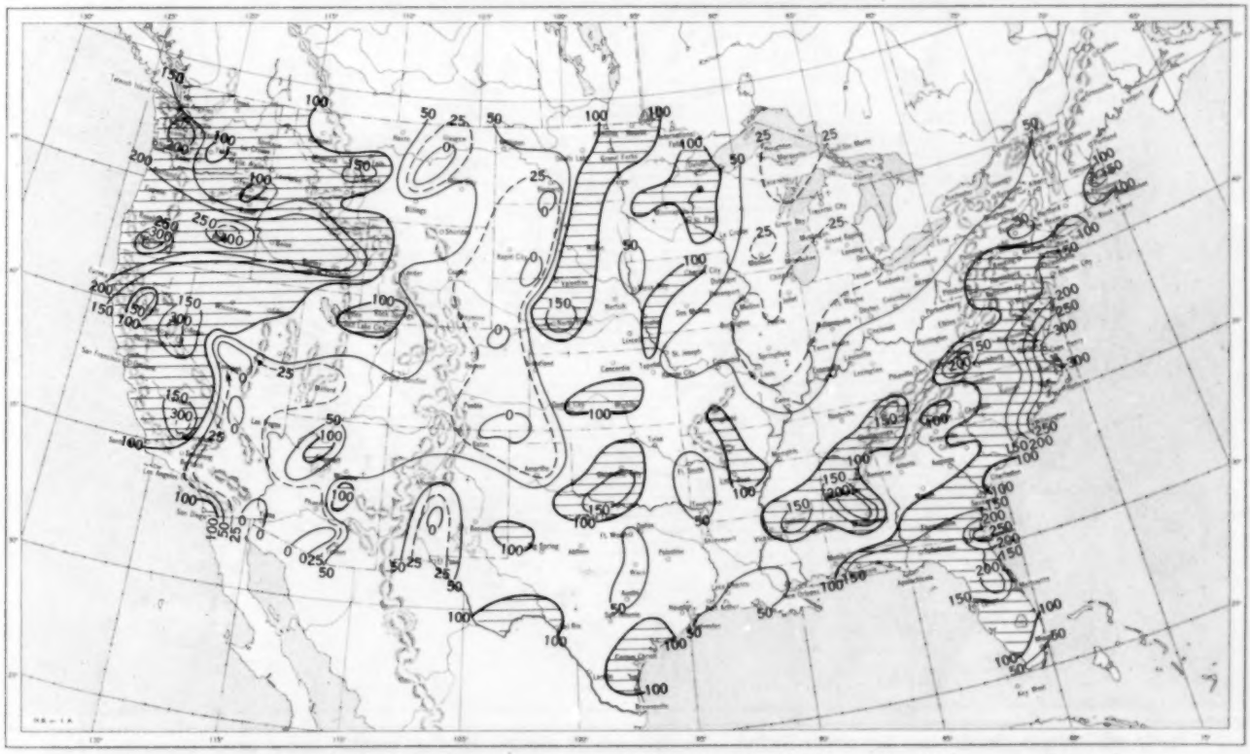

Scale of Shades
0 to 1 inch
1 to 2 inches
2 to 4 inches
4 to 6 inches
Over 6 inches
SCALE OF MILES
LAMBERT CONFORMAL PROJECTION TRUE AT 30° AND 60°

Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), October 1956.

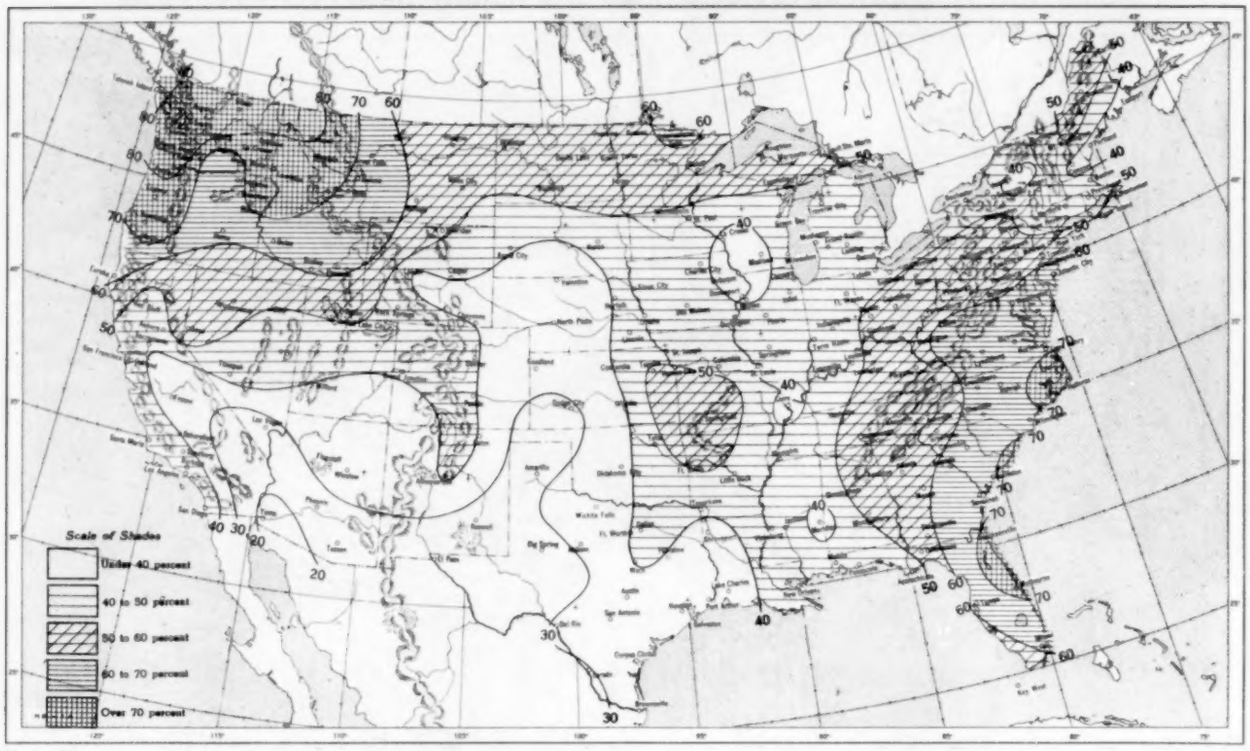


B. Percentage of Normal Precipitation, October 1956.

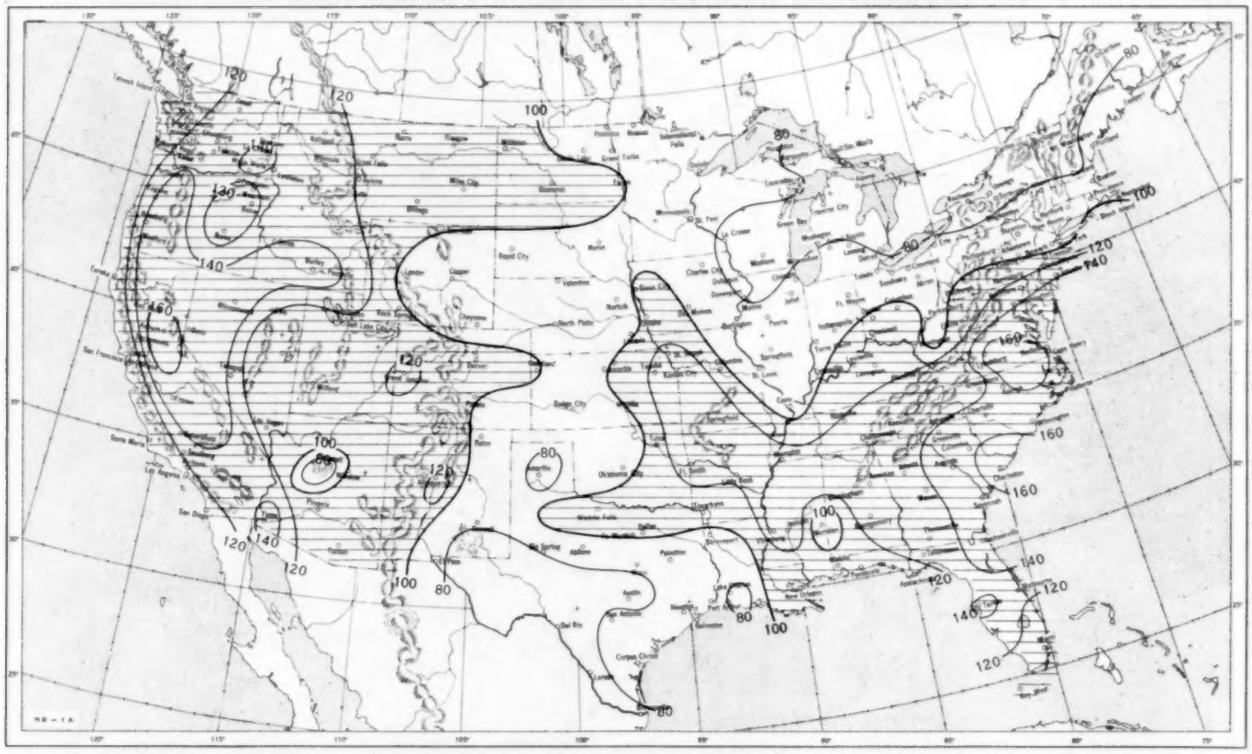


Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, October 1956.

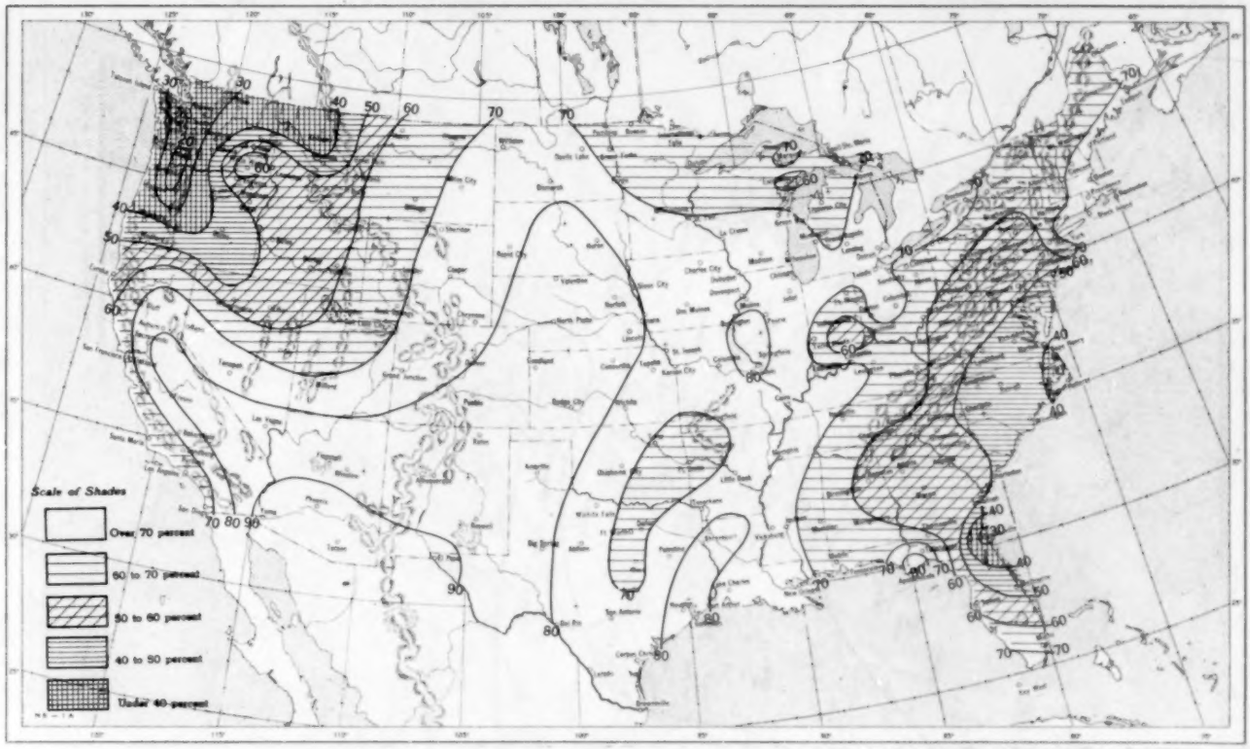


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, October 1956.

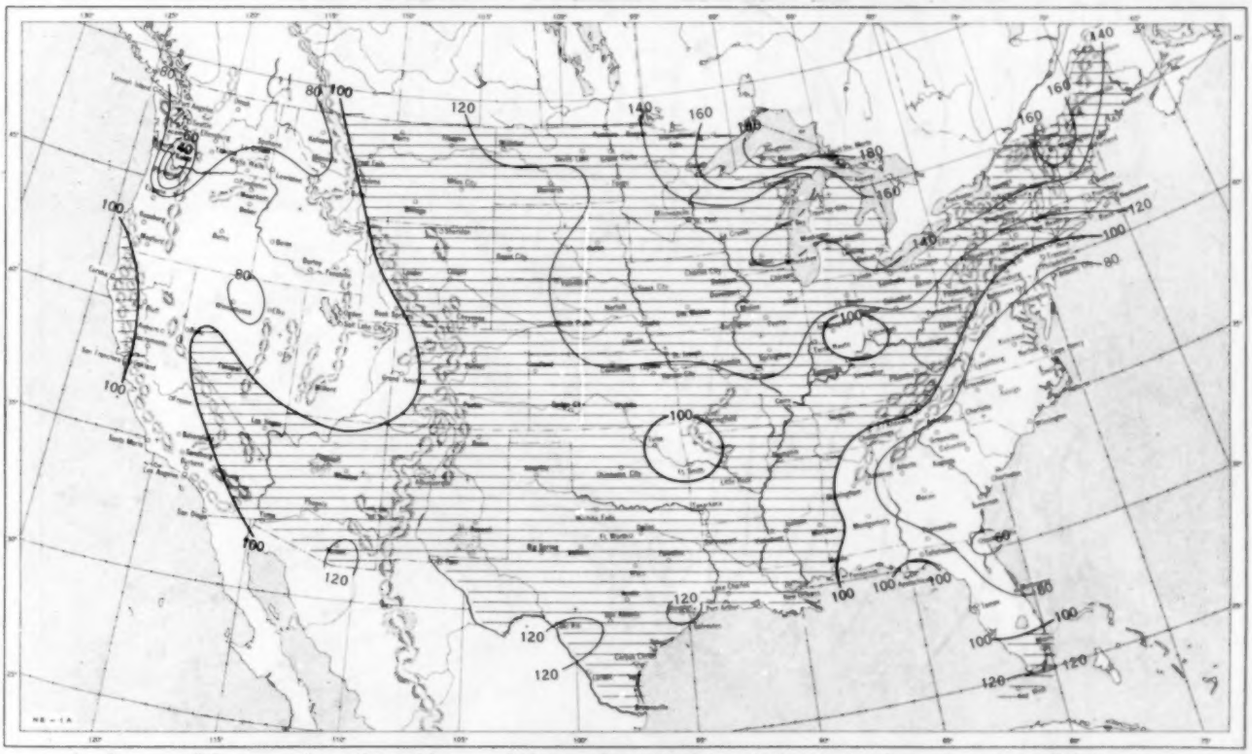


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, October 1956.



B. Percentage of Normal Sunshine, October 1956.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, October 1956. Inset: Percentage of Mean Daily Solar Radiation, October 1956. (Mean based on period 1951-55.)

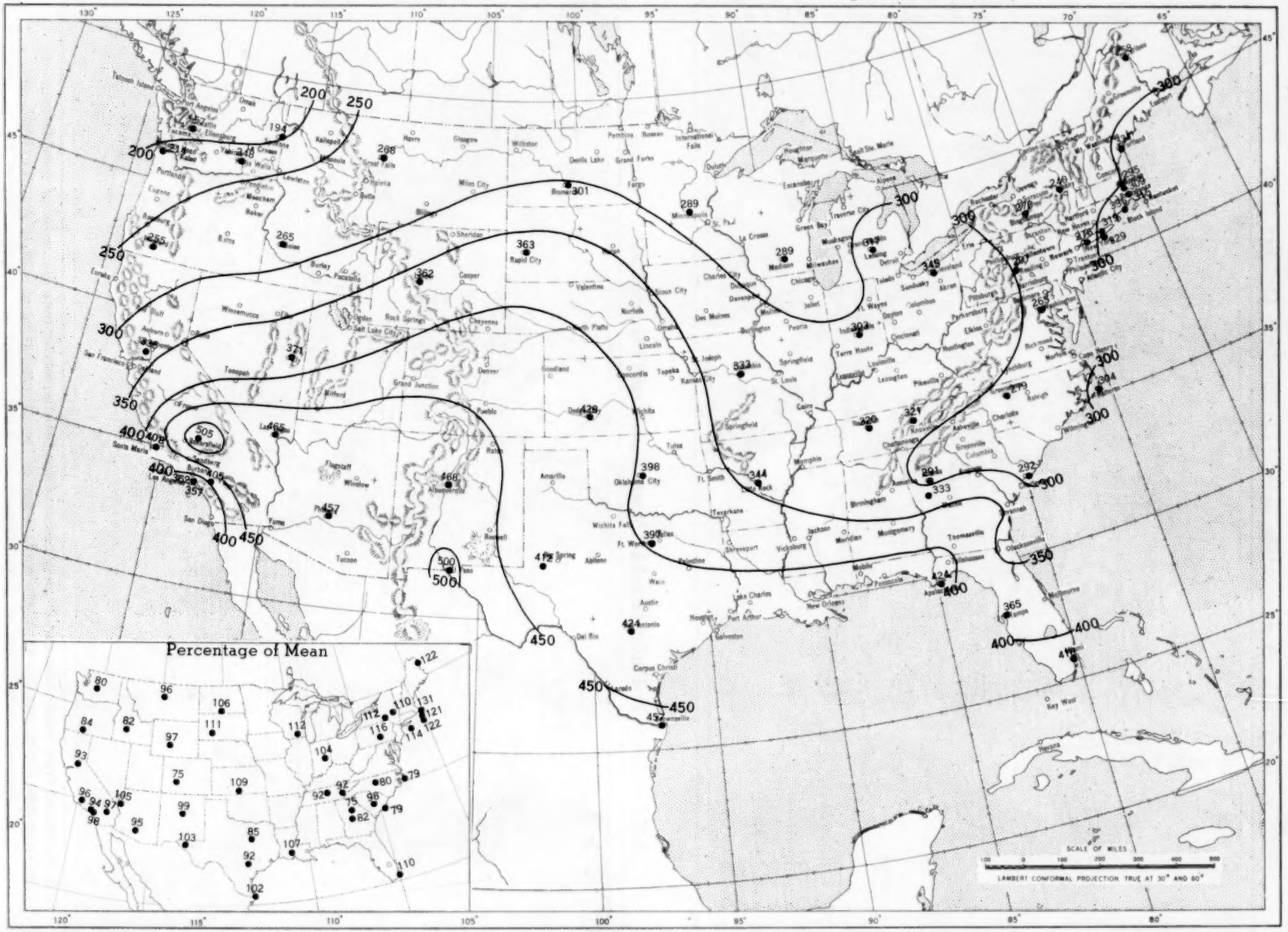
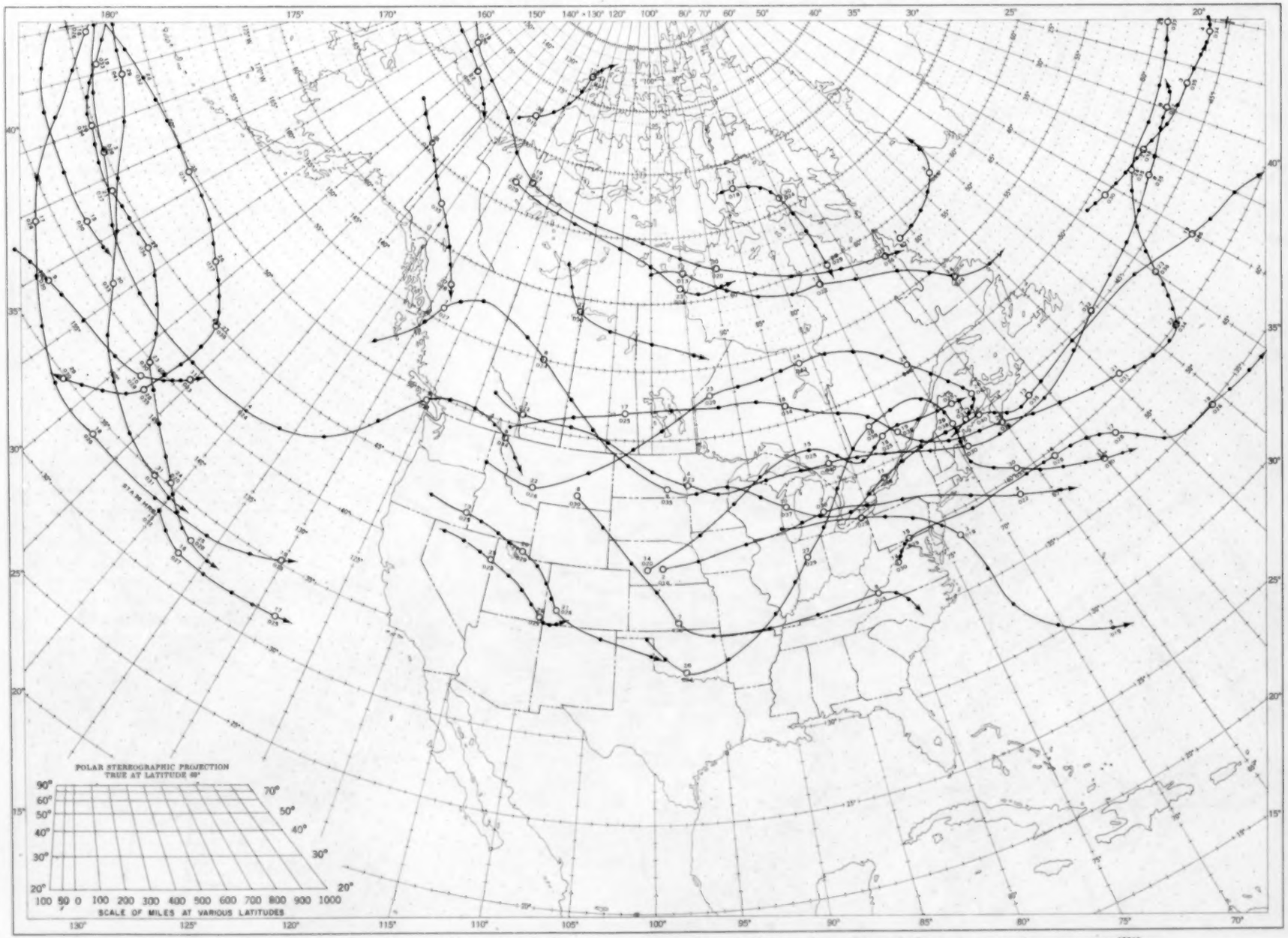


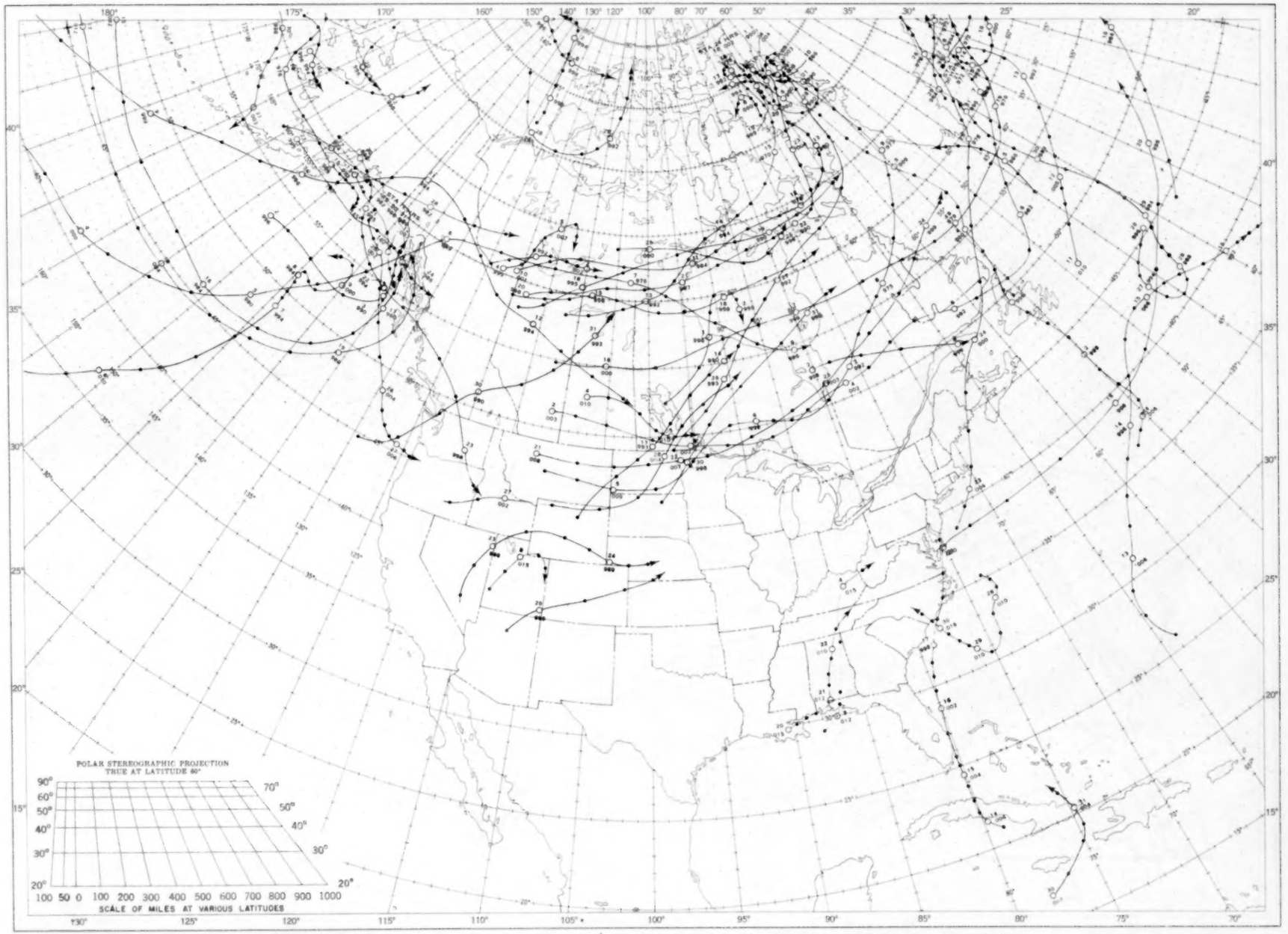
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, October 1956.



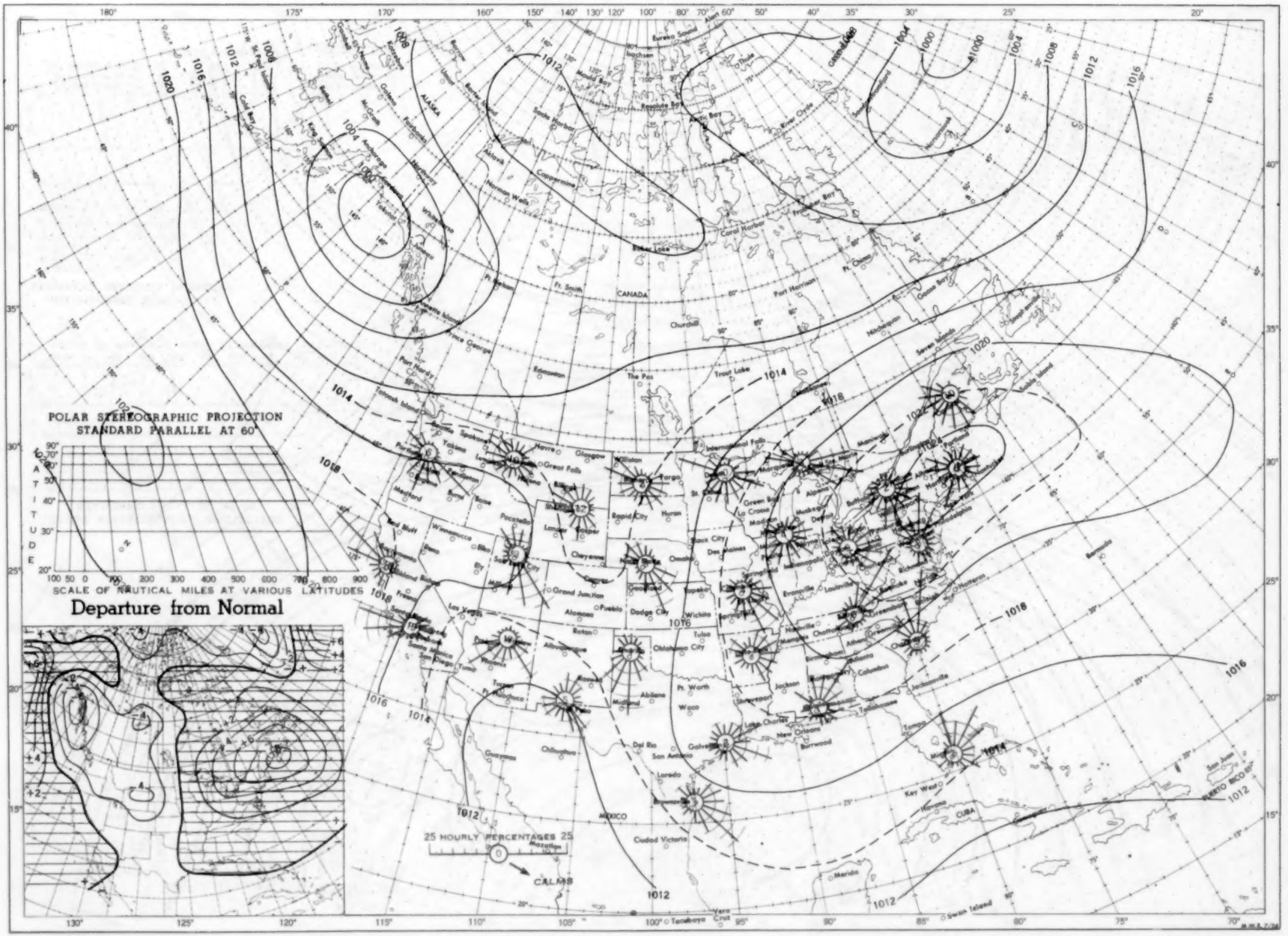
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, October 1956.


POLAR STEREOGRAPHIC PROJECTION
TRUE AT LATITUDE 60°
90° 60° 50° 40° 30° 20°
70° 50° 40° 30° 20°
100 50 0 100 200 300 400 500 600 700 800 900 1000
SCALE OF MILES AT VARIOUS LATITUDES

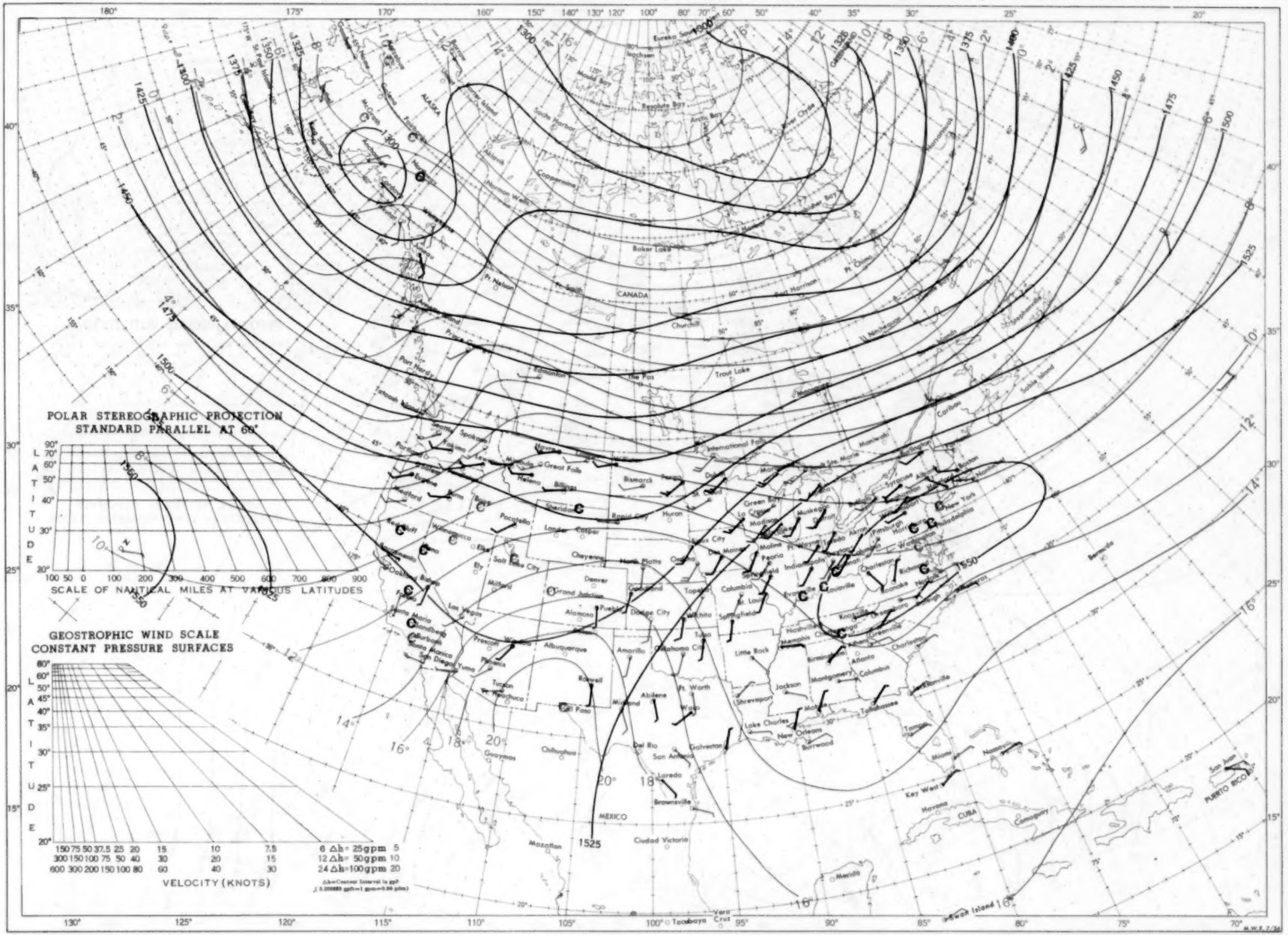
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, October 1956. Inset: Departure of Average Pressure (mb.) from Normal, October 1956.



Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

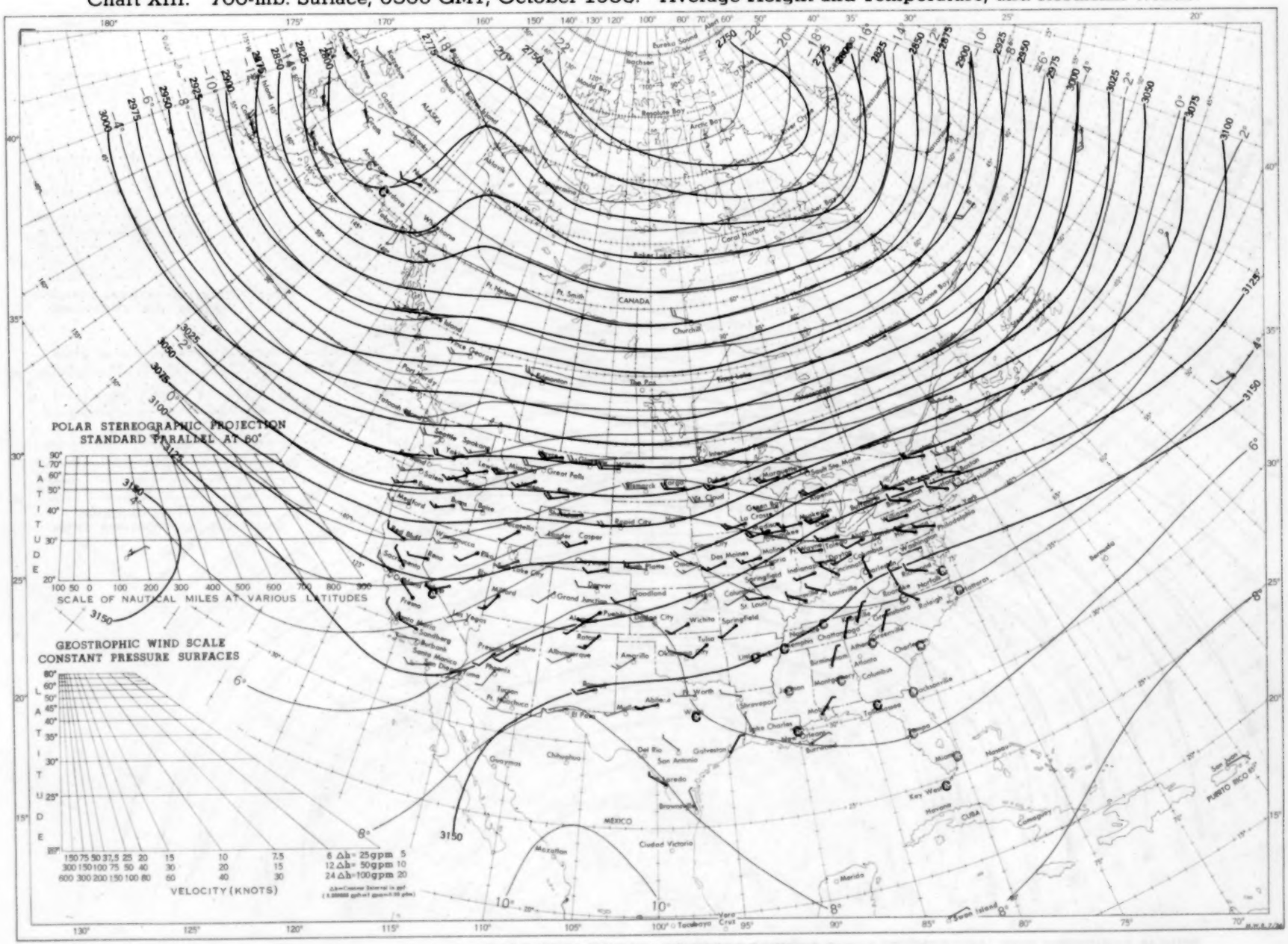
Chart XII. 850-mb. Surface, 0300 GMT, October 1956. Average Height and Temperature, and Resultant Winds.



Height in geopotential meters (1 g.p.m. = 0.98 dynamic meters). Temperature in °C. Wind speed in knots; flag represents 50 knots, full feather 10 knots, and half feather 5 knots. Winds shown in red are based on rawins taken at the indicated pressure surface and time. Those in black are based on pibals taken at 2100 GMT and are for the nearest standard height level.

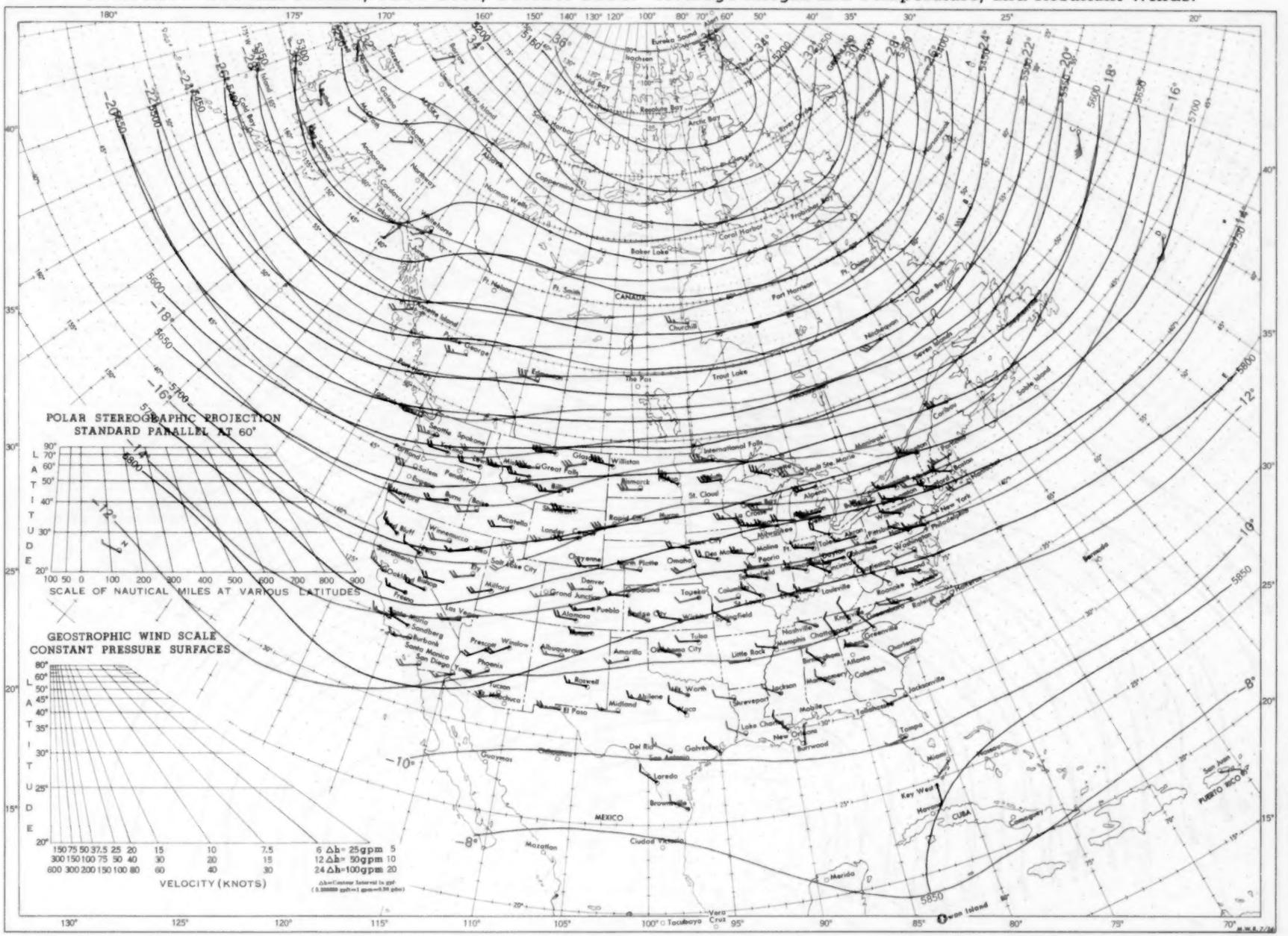
on pibals taken at 2100 GMT and are for the nearest standard height level.

Chart XIII. 700-mb. Surface, 0300 GMT, October 1956. Average Height and Temperature, and Resultant Winds.



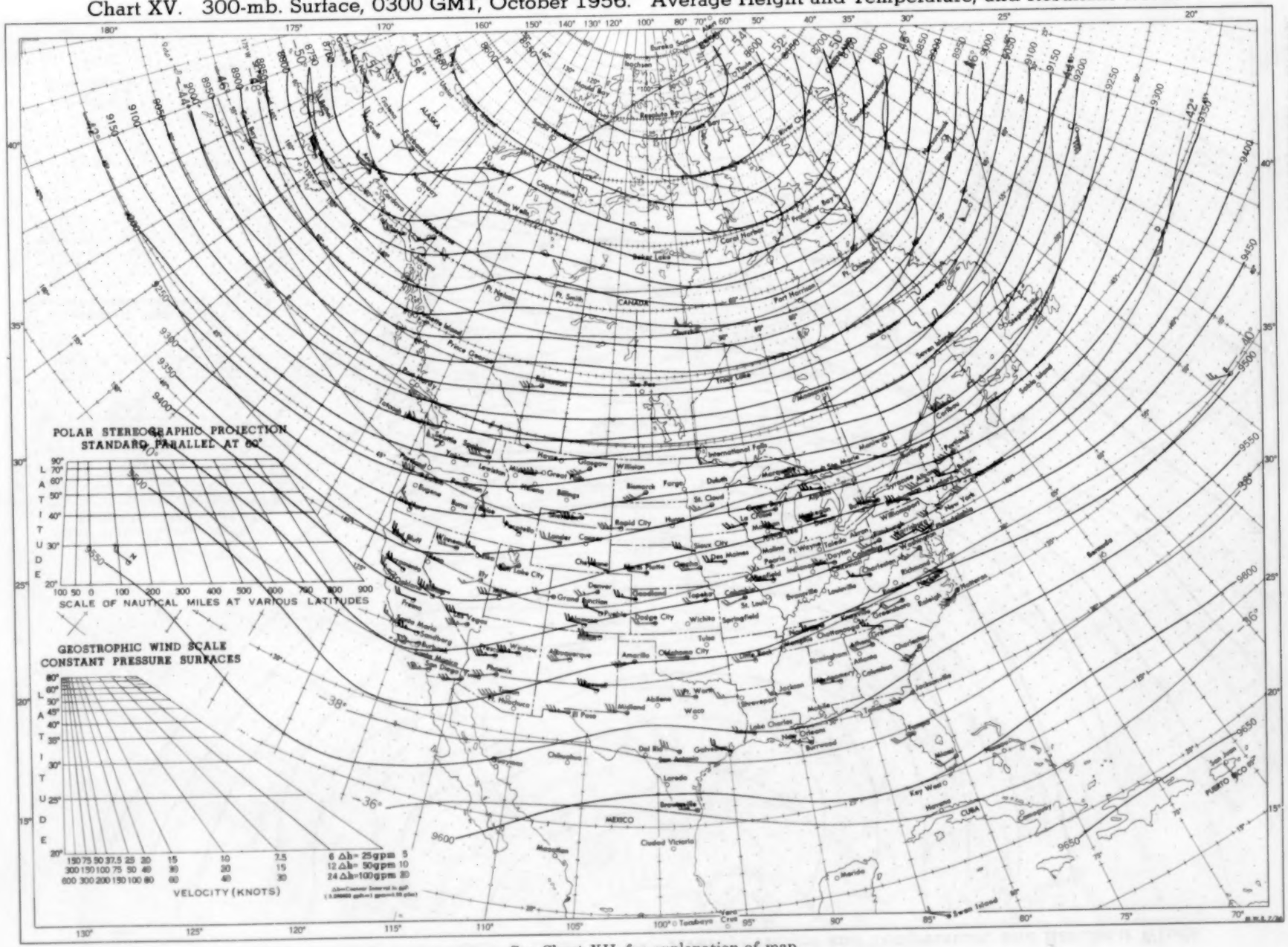
See Chart XII for explanation of map.

Chart XIV. 500-mb. Surface, 0300 GMT, October 1956. Average Height and Temperature, and Resultant Winds.



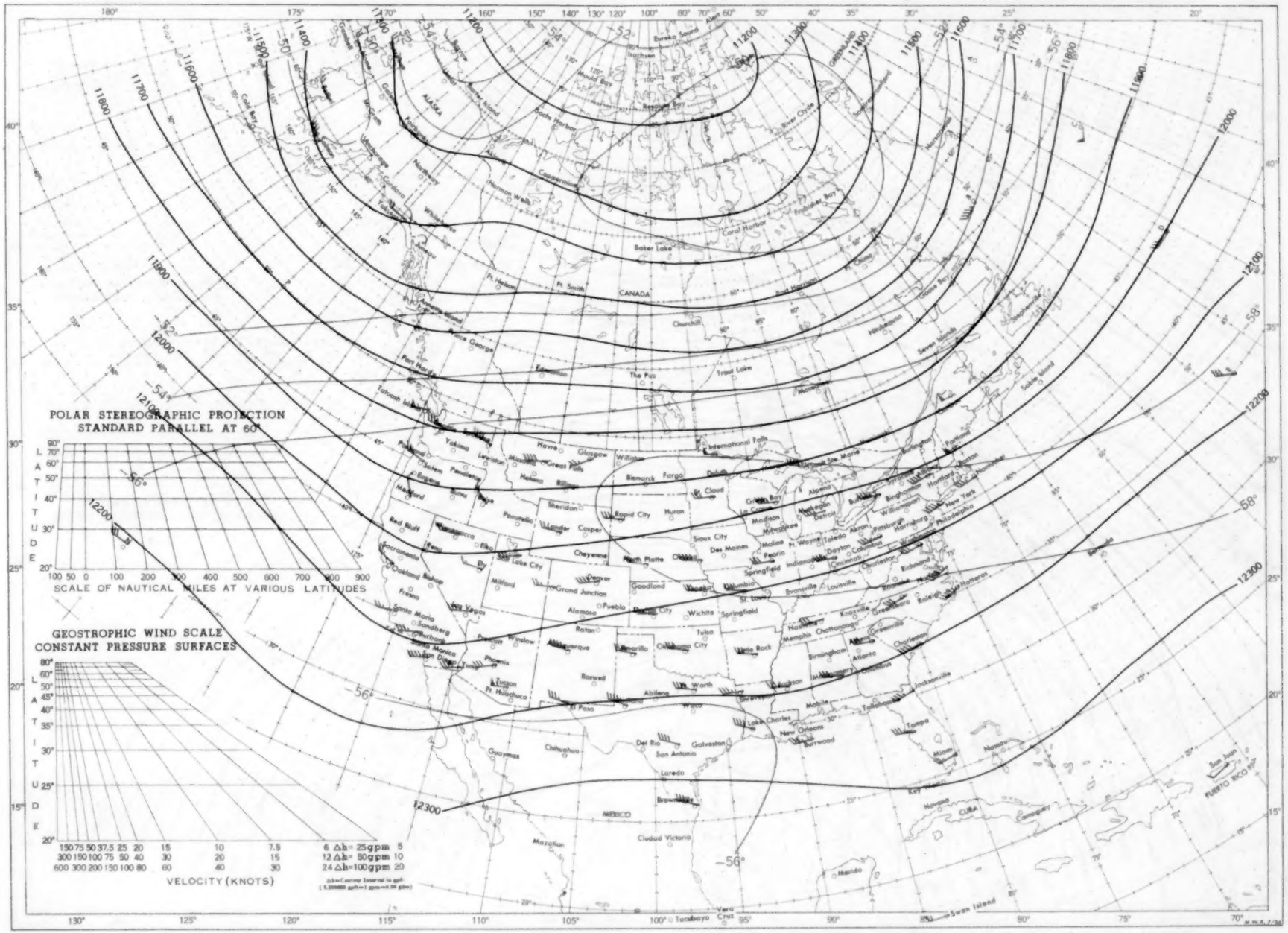
See Chart XII for explanation of map.

Chart XV. 300-mb. Surface, 0300 GMT, October 1956. Average Height and Temperature, and Resultant Winds.



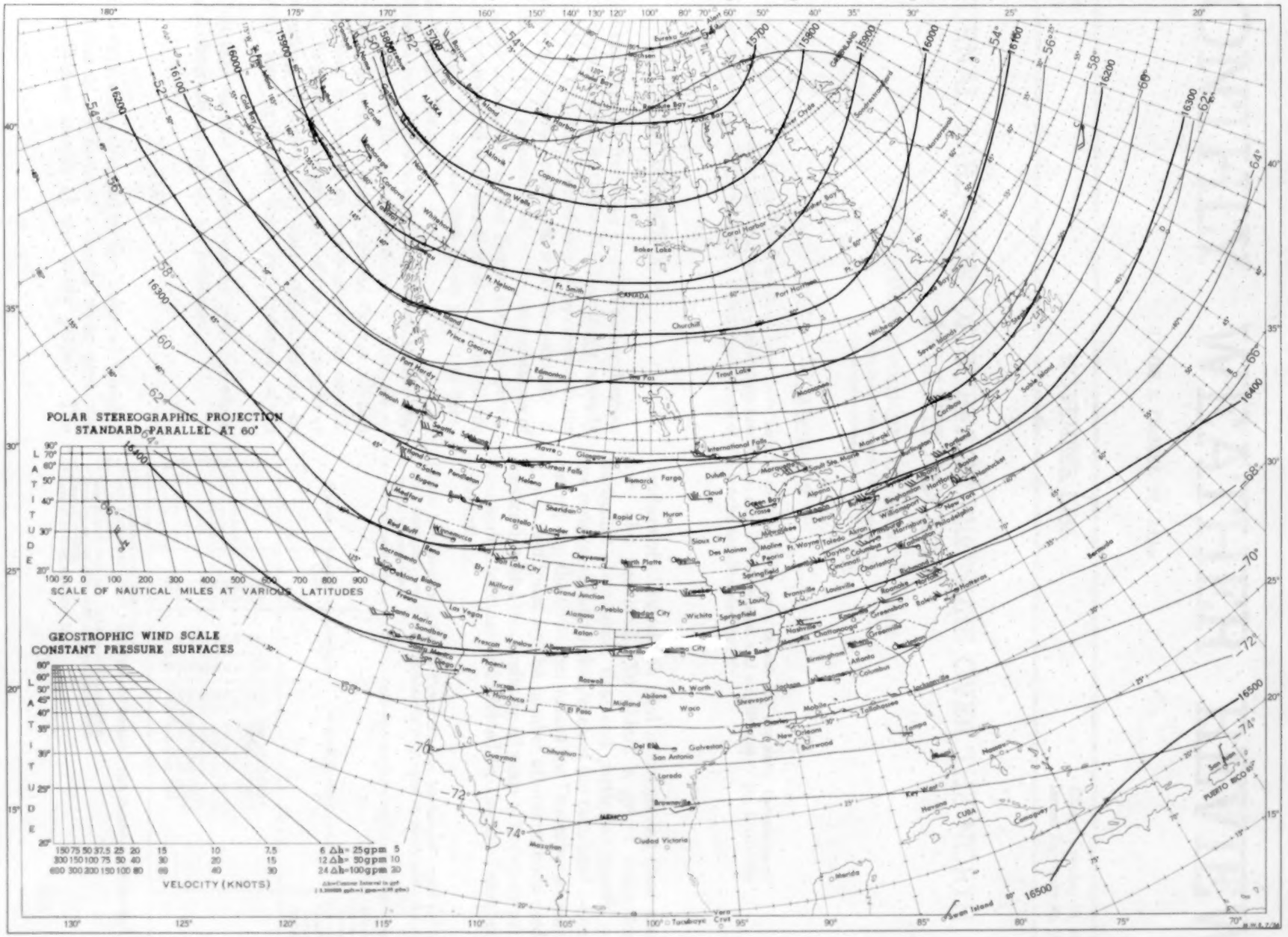
See Chart XII for explanation of map.

Chart XVI. 200-mb. Surface, 0300 GMT, October 1956. Average Height and Temperature, and Resultant Winds.



See Chart XII for explanation of map. All winds are from rawin reports.

Chart XVII. 100-mb. Surface, 0300 GMT, October 1956. Average Height and Temperature, and Resultant Winds.



See Chart XII for explanation of map. All winds are from rawin reports.